Derksen, A. J. 1980

Evaluation of Fish Passage Through Culverts at the Goose Creek Road Crossing Near Churchill, Manitoba, in April and May, 1977.

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ABSTRACT

Fish movements and flows at the Goose Creek road crossing near Churchill, Manitoba, were monitored from April 29 to May 20, 1977. The crossing consists of five arch-rib multiplate culverts which are 27.4 m long with an opening of 2.7 x 3.9 m. There are three culverts in the east channel and two in the west.

The mean daily discharge recorded in the east channel of Goose Creek during the monitoring period was 16.4 $m^3 s^{-1}$. An average daily discharge of 8.4 $m^3 s^{-1}$ was recorded in the west channel. Average water velocities at the downstream ends of the culverts exceeded 0.91 m s^{-1} in all five culverts throughout the 22-day monitoring period.

A total of 1044 fish were captured in hoop nets set immediately downstream of the crossing. Longnose suckers constituted 69.4 per cent of the catch. Other species caught included burbot, lake whitefish, round whitefish and Arctic grayling. Most (69%) of the fish were caught from the west channel.

None of the 13 Arctic grayling tagged and released below the Goose Creek crossing was recaptured, although 30 unmarked grayling were netted upstream of the culverts. Twenty-six of the 198 pike were recovered; 17 recoveries were made during the monitoring period.

Only four of the 17 recoveries were from upstream of the crossing. These four fish may have moved through the west channel culverts. Twenty-six of the 725 longnose suckers were recaptured; 16 during May, 1977. Only one recovery was made upstream of the culverts.

From the observed data and comparisons with the swimming performances of similar fish species as described in the literature, it was concluded that water velocities experienced in the Goose Creek culverts in 1977 presented a near-total barrier to the upstream migration of spring spawning fishes (Arctic grayling, northern pike and longnose suckers) in Goose Creek.

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INTRODUCTION

During the course of the Lake Winnipeg, Churchill and Nelson Rivers Study, some special problems were anticipated in the Churchill River estuary as a result of Manitoba Hydro's Churchill River Diversion project. Two concerns related to the water supply for the Town of Churchill and to recreational aspects in the Churchill area (LWCNR Study Board, 1975).

Diversion of the Churchill River at Southern Indian Lake during the winter has resulted in substantially reduced flows in the lower Churchill River. The combination of low flows in the lower Churchill River and high tides may have resulted in the intrusion of brackish water into the area of the former water supply intake for Churchill. Low ice cover levels may also have damaged the old intake pipe. To circumvent this problem, Manitoba Hydro, with the aid of consulting engineers, undertook in 1976 to relocate the water supply intake approximately 7.0 km upstream on the Churchill River. This relocation necessitated construction of a service road which crossed Goose Creek, a small tributary to the Churchill River near Churchill. Fig. 1 illustrates the pre-existing water supply intake, service, a major portion of Goose Creek, and the road crossing. All construction was completed before 1977, when the Churchill River Diversion went into operation.

Prior to the Diversion, Churchill residents used the lower Churchill River area extensively as a recreational area. Small boat navigation was possible as far as approximately 97 km upstream from Churchill. This reach was used as a cottage area as well as for camping,

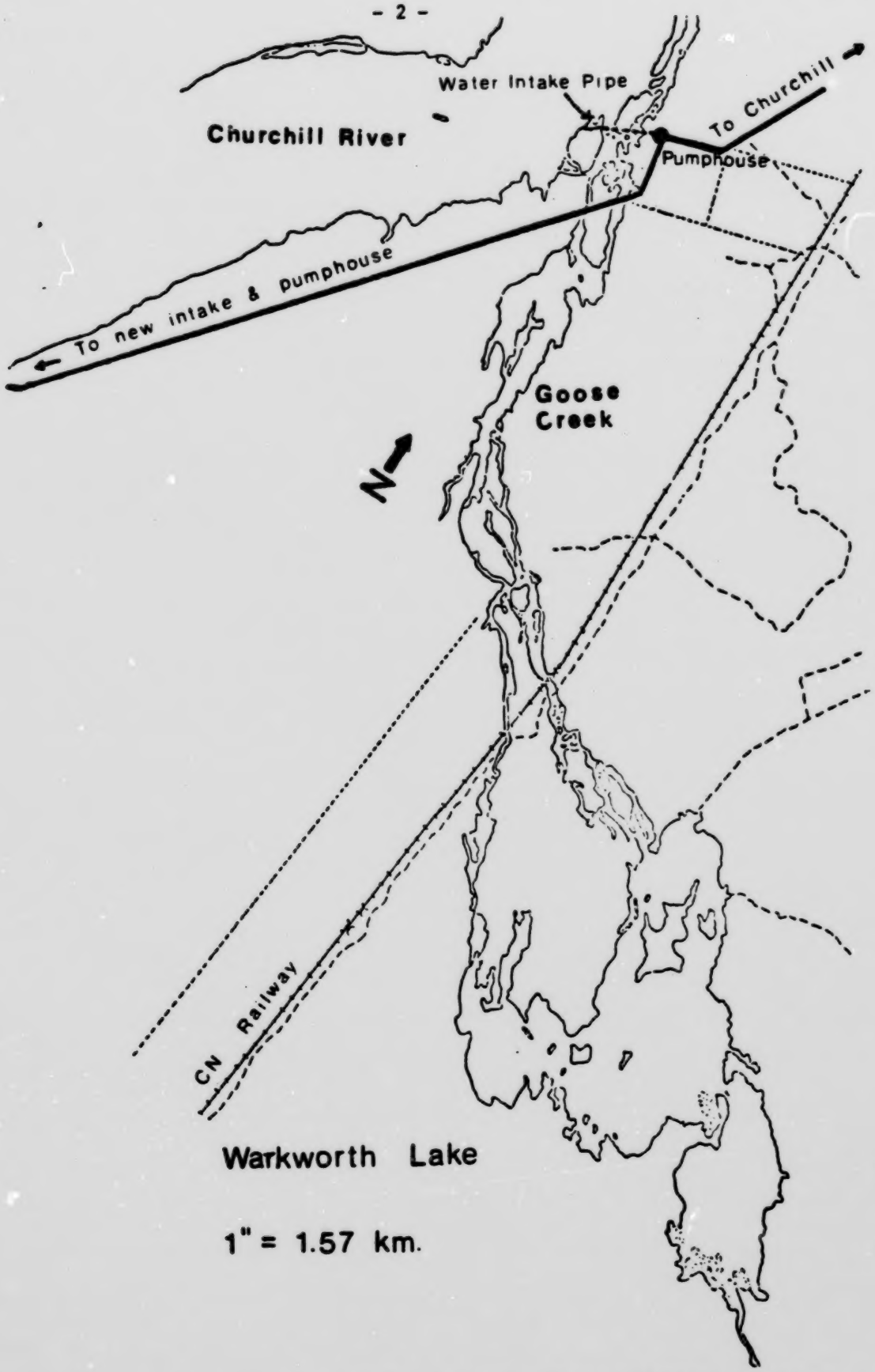

Figure 1. A general map showing Goose Creek and its relationship to the Churchill River and the service road to water supply intakes.

sport fishing and hunting. With the Churchill River Diversion in operation, recreational opportunities on the lower Churchill River have disappeared or been severely curtailed because of both reduced access and direct environmental impacts on fish and wildlife resources. These changes may result in increased pressure by recreational demands upon other accessible areas around Churchill. One such area is Goose Creek.

Goose Creek has provided reasonably good fishing for Arctic grayling (Thymallus arcticus). From 1958 to 1974, it produced about 6.5 per cent of the trophy-sized grayling in Manitoba and ranked fifth relative to other trophy-grayling producing areas in the Province (Gillies, 1975). Northern pike (Esox lucius)and occasionally brook trout (Salvelinus fontinalis) are also angled in Goose Creek. Improper design and placement of the crossing on Goose Creek could jeopardize fish populations utilizing the stream and reduce the recreational opportunities of Churchill residents.

On January 19, 1976, a Manitoba Hydro official contacted the author to arrange a meeting to discuss provisions for fish passage at the Goose Creek crossing. Representatives of the Department of Renewable Resources and Transportation Services and the federal Fisheries and Marine Service (FMS), now the Department of Fisheries and Oceans, met with Manitoba Hydro officials and their consultants (W.L. Wardrop and Associates, Ltd.) on February 6. At this meeting, Manitoba Hydro expressed their intention to employ culverts in the Goose Creek crossing. Fisheries personnel outlined some of the problems presented by culverts to fish populations and

expressed their concern that culvert design should permit free upstream movement of fish, particularly Arctic grayling, into Goose Creek (Derksen, 1976 a and Katopodis 1976 a).

A second meeting was held May 5, 1976, at which time consultant's plans for the Goose Creek crossing were reviewed. Information provided by the consultants indicated the proposed Goose Creek crossing design would accommodate Arctic grayling movements through the culverts (Derksen, 1976b). Written plans or blueprints were not received, nor presented to FMS for review and comment.

FMS personnel subsequently acquired additional information on the Goose Creek crossing design from the consultants. An assessment of this information by FMS indicated that " . . . a complete or unacceptably high degree of blockage to spring fish migrations . .", including grayling would occur at the Goose Creek crossing (Katopodis, 1976b).

Following the FMS assessment, a third meeting was held August 26, 1976. At this meeting, those responsible for the Goose Creek crossing design expressed some doubt over the inadequacy of the design. The suggestion of placing additional culverts in the crossing was dismissed because of the high cost ($150,000 to $250,000). Because of the high cost for additional culverts and differing opinions on the crossing design's adequacy, it was decided that monitoring should be conducted in 1977 to ascertain whether or not blockage of fish movements at the crossing would in fact occur.

A proposal to monitor flows and fish movements at the Goose Creek crossing was developed. The principal objectives of the study were to measure daily water velocities through the major culverts in the crossing and to determine the effect of these velocities on fish moving upstream into Goose Creek during the spring run-off either to spawn or feed. Monitoring began on April 27 and terminated May 20, 1977. Although some additional spring flow measurements were made in 1978 and 1979, this report presents only the 1977 results.

DESCRIPTION OF THE GOOSE CREEK CROSSING

Goose Creek, which has an estimated drainage area of 620 km^2, drains Warkworth Lake and enters the Churchill River approximately 11 km upstream from Churchill (Fig. 1). Discharge rates of Goose Creek have never been previously recorded, but the 24 and 50-year floods[1] (Q_{25} and Q_{50}) have been estimated to be 79.2 $m^3 s^{-1}$ and 92 $m^3 s^{-1}$, respectively (Katopodis, 1976b).

The Goose Creek crossing, which was constructed in 1976, is situated about 1.3 km from the Churchill River (Fig. 2). At this point, the creek consists of two major channels. The east channel is approximately 160 m wide and the west channel width is about 80 m.

Five large culverts were placed in the crossing; three in the east channel and two in the west. These culverts are arch rib, multiplate structures, 27.4 m long, with an opening of 2.7 x 3.9 m. According to estimates determined by the consultants, the main culverts in the Goose Creek crossing have the capacity to handle a stream flow of 72.2 $m^3 s^{-1}$ (Stratton, 1976). Estimated flow characteristics for the Goose Creek culverts are presented in Tables 1 and 2. Fig. 3 compares the estimated flow characteristics of the Goose Creek culverts to FMS guidelines for stream crossings.

In addition to the five large culverts in the Goose Creek crossing, 37 culverts ranging in size from 0.61 to 1.23 m (diameter) were placed at various points along the 7.2 km stretch of new access

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[1] The expressions 25-year and 50-year floods may be defined as the maximum stream discharges which have expected return periods of 25 and 50 years, respectively. Return period may be defined by $T = \frac{1}{p}$, where p is the probability an event will equal or exceed a given magnitude.

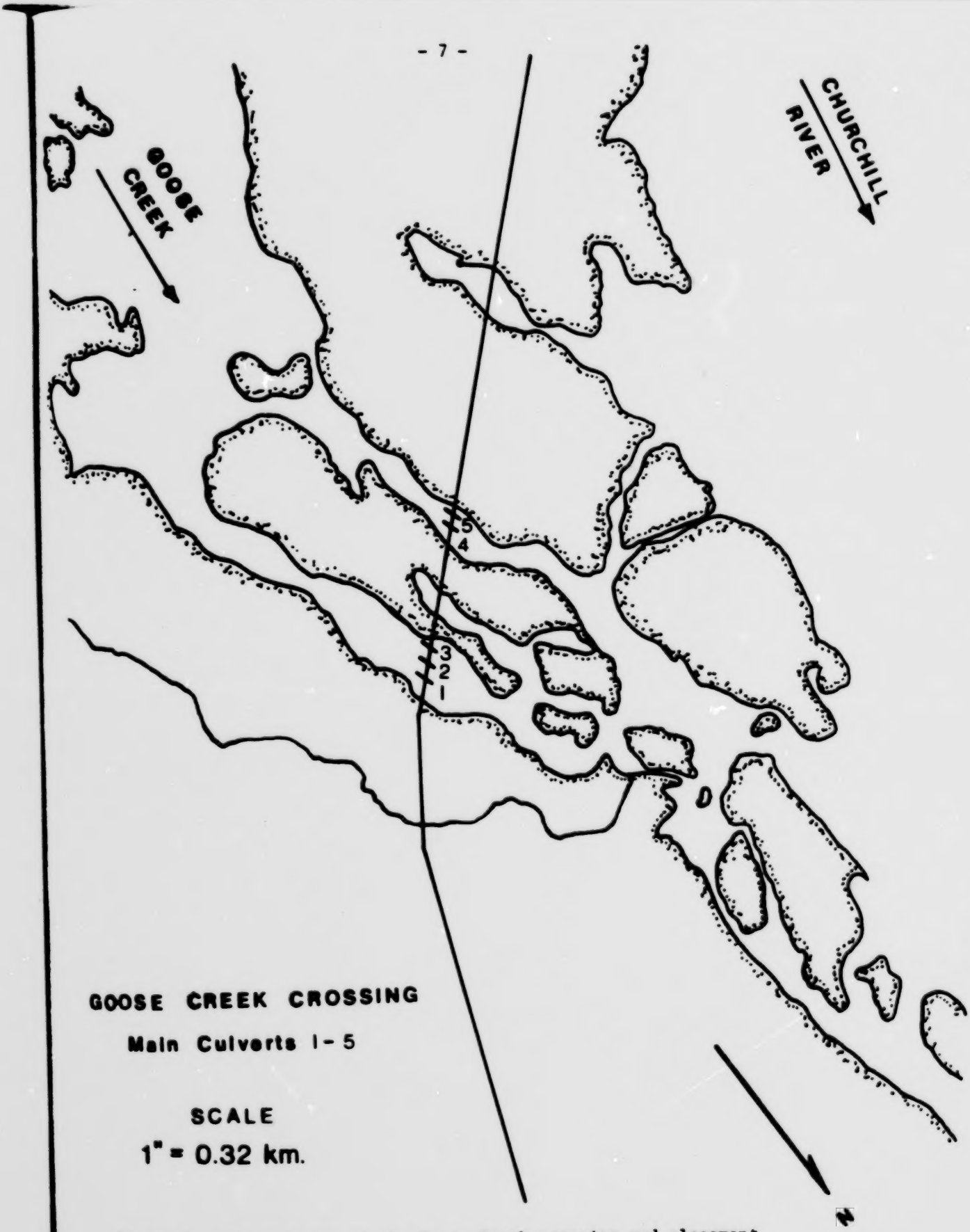

Figure 2. The location of the Goose Creek crossing and placement of the five main culverts.

Table 1. Estimated flow characteristics for Goose Creek culverts for various discharge rates (from Stratton, 1976).

Total Stream Discharge ($m^3 s^{-1}$)	Discharge/Pipe ($m^3 s^{-1}$)	Depth of flow (m)	Velocity ($m s^{-1}$)
77.8	15.5	2.3	2.04
72.2*	14.4	2.5	1.83
56.6	11.3	1.6	2.01
49.0**	9.8	1.5	1.95
28.3	5.7	1.1	1.68
14.2	2.8	0.8	1.37

* Culverts flowing full
** 7-day delay flow

Table 2. Estimated flow velocities and volumes for Goose Creek culverts for various headwater and tailwater depths (from Donison, 1976).

Headwater depth (m)	Tailwater depth (m)	Average velocity ($m\ s^{-1}$)	Approx. Q $m^3\ s^{-1}$
0.61	0.61	0	0
0.61	0.46	0.91	7.64
1.52	1.37	0.64	16.98
1.52	0.91	1.31	34.53
1.52	0.61	1.95	49.04
2.44	1.83	1.07	44.15
2.44	1.22	1.71	70.75

road (Donison, 1976). These smaller culverts were installed to carry off sheet flows during periods of flooding.

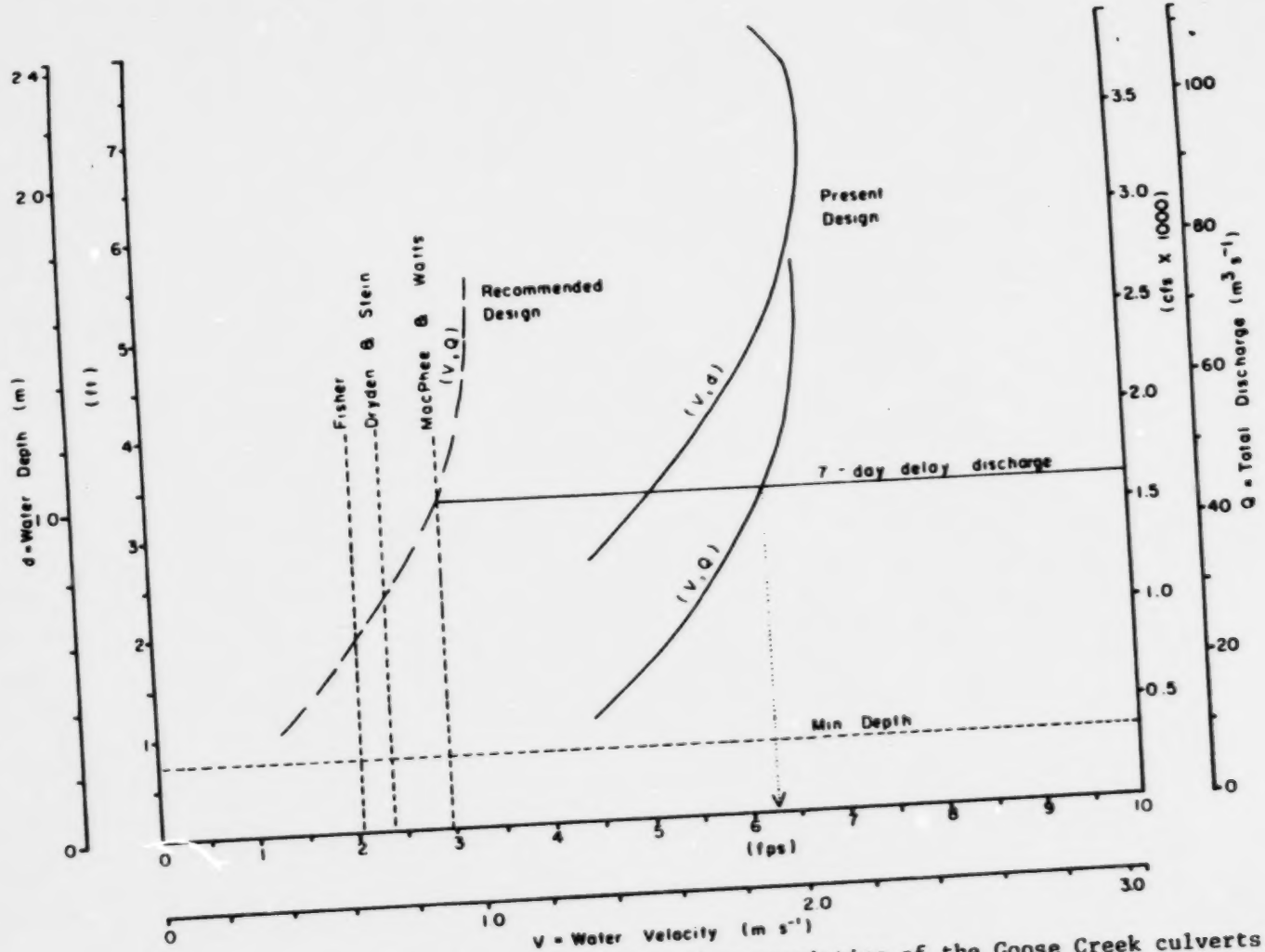

Figure 3. Comparison of the estimated flow characteristics of the Goose Creek culverts to the Fisheries and Marine Service guidelines for culverts which will permit fish passage (from Katopodis, 1976b).

METHODS

Hydrometric Monitoring

Water velocities were monitored only at the five main culverts in the Goose Creek crossing. Velocities were monitored daily during April 29 to May 20, 1977, except on May 14 and 15 when no measurements were taken at culverts 4 and 5. Water velocities were recorded with a Guerney-Price current meter stabilized with a 13.6 kg weight.

Water velocities were measured at the downstream ends of the culverts. Velocity measurements were made at three points; at the center and approximately 1 m from either side of the culvert. At each of these points, velocities were recorded at depths of approximately 0.3 and 1.5 m below the water surface. Velocities recorded at these points and depths were averaged to obtain the mean water velocity for each culvert. Velocities are calculated in terms of feet per second (fps).

In addition to measurements of water velocities, water levels (in feet) were recorded at the upstream and downstream ends of each culvert. Average daily discharges determined as cubic feet per second (cfs) in the east and west channels of Goose Creek were estimated from the water velocity data. Gauge levels above and below the crossing were also recorded. Within the text of this report, hydrometric measurements have been presented as metric units. In some cases, Imperial equivalent units are presented in parentheses.

Biological Monitoring

Biological monitoring at Goose Creek was conducted from April 27 to May 20, 1977. Monitoring basically consisted of capturing, tagging

and releasing fish below the Goose Creek crossing and attempting to recapture tagged fish upstream of the crossing. Special emphasis was placed on those species which were apparently moving into Goose Creek to spawn; i.e. Arctic grayling, northern pike and longnose sucker.

A hoop net was set immediately downstream of culvert 1 on April 28 and a second hoop net was placed downstream of culvert 4 on May 6 (Fig. 4). Each hoop net consisted of two rectangular hoops (0.9 x 1.5 m), six circular hoops (diameter-0.9 m) and 3 m long wings. On the hoop net in the east channel an extra 9.1 m lead was attached to the midstreamward wing so that the net would fish a greater portion of the stream. Mesh size of the webbing on the body and wings of the hoop nets was 2.54 cm (bar measure). Hoop nets were checked in the morning and afternoon of each day. Captured fish were tagged and released. Fish were tagged with numbered Floy spaghetti tags. Only a small percentage of burbot caught in the hoop nets were tagged. Length measurements of all tagged fish were recorded.

To recapture the tagged fish, gill nets were set in the east and west channels a short distance (90 m) upstream of the culverts (Fig. 4). Each of these sets consisted of 7.6 m of 7.6 cm mesh (stretched measure). Difficulty was experienced in the early gill netting in the east channel because of ice and fouling of the gill net with algae and debris. These gill nets (1-3) were lifted once each day. In addition to the above gill netting, gill nets (5.1 and 7.6 cm mesh) were set downstream of the crossing on May 15 and 16 (Fig. 4). This netting was done to determine if major fish movements from the Churchill River into Goose Creek were still

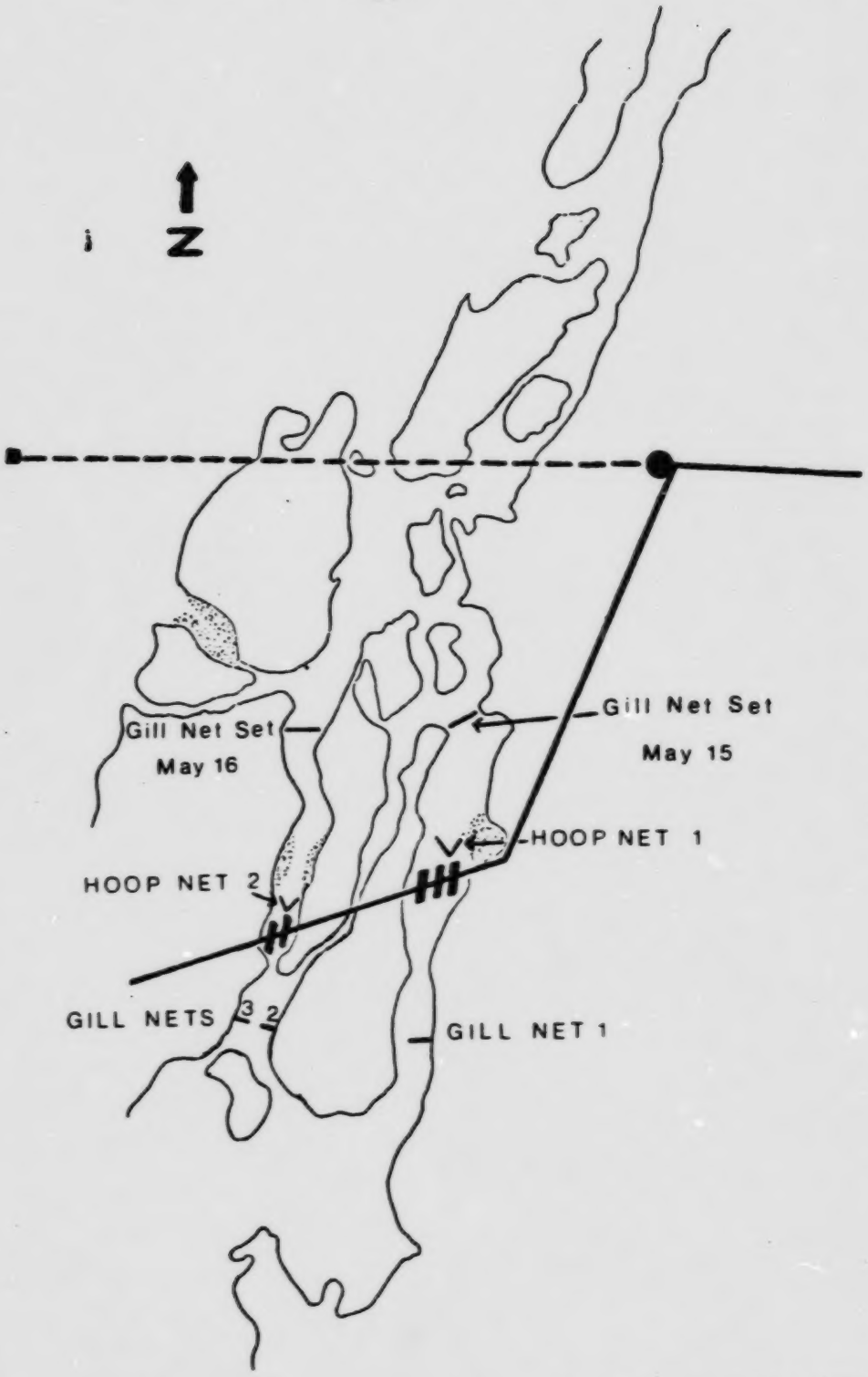

Figure 4. Netting locations in the vicinity of the Goose Creek crossing to determine fish movements through culverts.

occurring. A 38 m gill net (7.6 cm mesh) was set in Warkworth Lake on May 18 (Fig. 5). This set was made to determine if large numbers of tagged fish had moved into Warkworth Lake. Further details of the hoop netting and gill netting operations at Goose Creek are given in Appendix B.

Surface water temperatures in Goose Creek were recorded daily beginning on May 3. Mean daily air temperatures were obtained from the Churchill Airport.

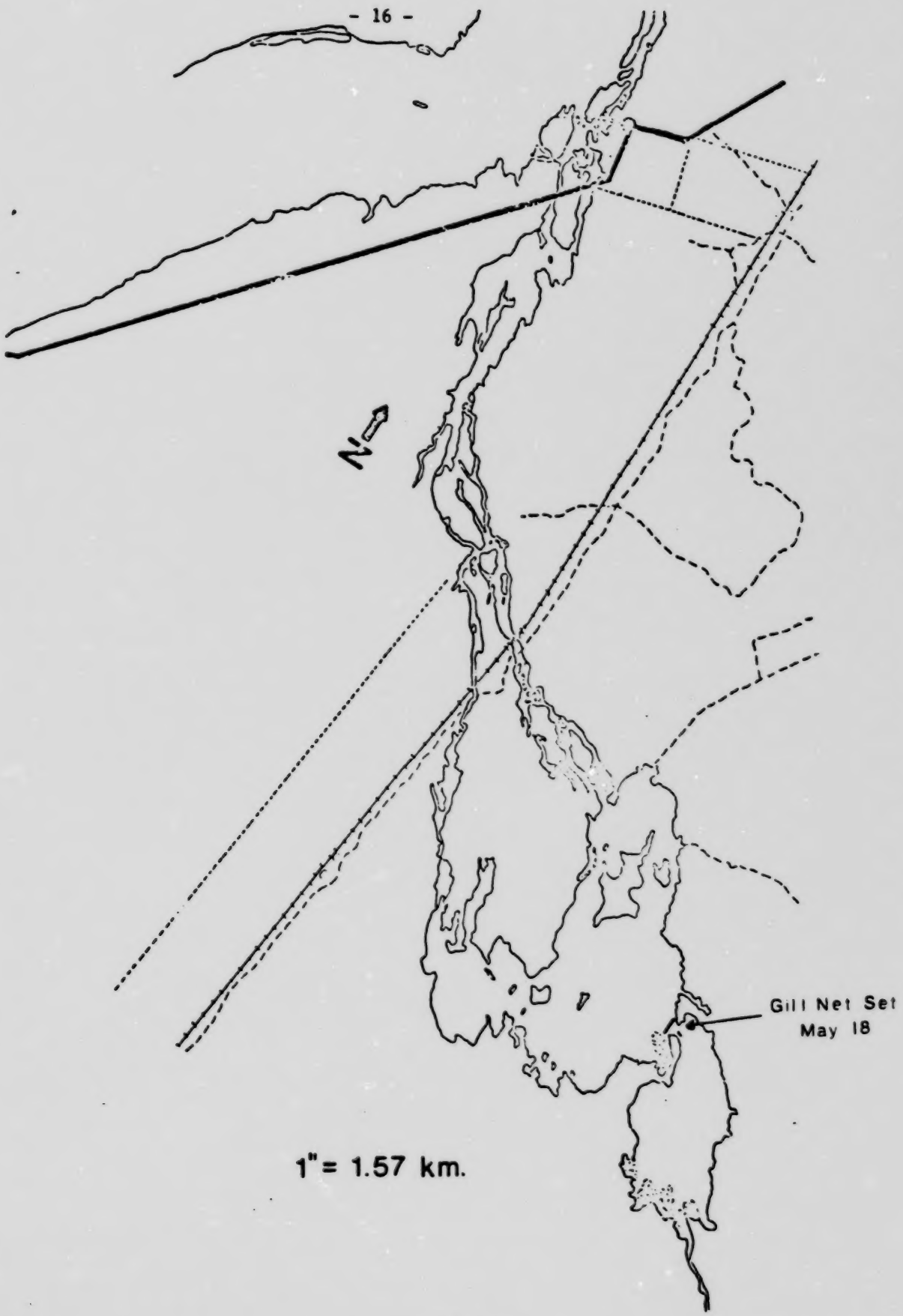

Figure 5. Location of gill net set in Warkworth Lake.

RESULTS

Hydrometric Monitoring

Raw data compiled during the monitoring of the Goose Creek culverts are presented in Appendix A.

Discharges were higher in the east channel than in the west channel of Goose Creek (Fig. 6). Average daily discharge in the east channel was 16.4 $m^3 s^{-1}$ while that in the west channel was 8.4 $m^3 s^{-1}$. The highest discharge (20.5 $m^3 s^{-1}$) observed during the monitoring period was in the east channel on April 29, the first day of monitoring. Higher discharges probably occurred several days before. Flows in Goose Creek tended to reduce gradually throughout the observation period (Fig. 6). Low discharges were observed during two time periods; April 30-May 1 and May 14-15. During the first of these periods, Goose Creek froze with as much as a 5 cm ice cover forming overnight. This ice cover lasted until May 5. Around May 14-15, an ice jam formed on the Churchill River and caused water to backup into Goose Creek. The backwater effect was most evident in the west channel where zero or reversed flows were noted. Although there was open water on Goose Creek from May 5 onward, winter ice did not leave until May 8. Up until that time, winter ice, at least within the vicinity of the crossing, lay anchored to the stream bottom.

There was no large difference between water gauge levels upstream and downstream of the crossing. Except for several days, water levels upstream of the crossing were less than 0.3 m (1 ft) higher than downstream water levels. Ponding in the west channel was generally less marked than in the east channel (Fig. 7).

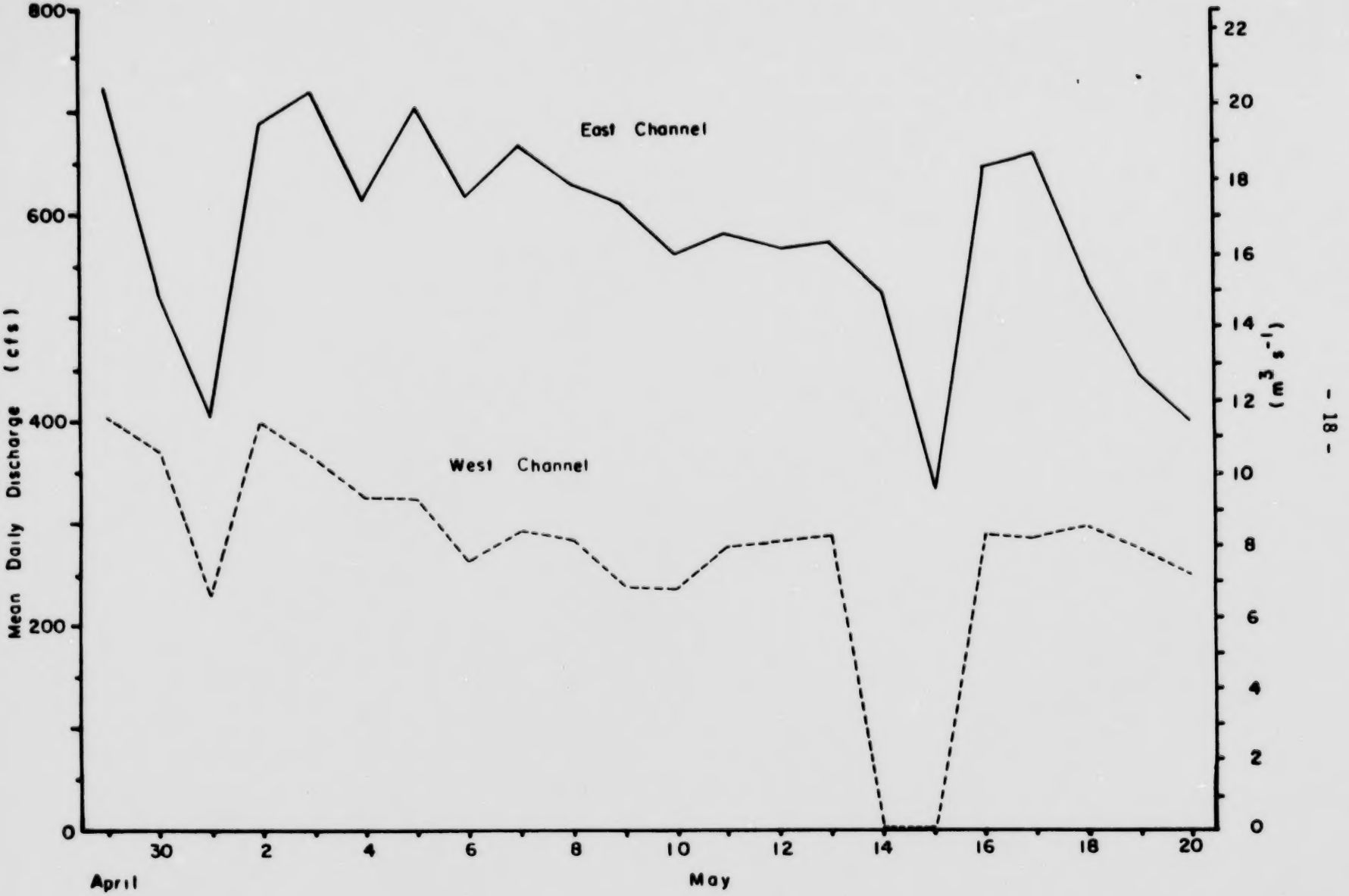

Figure 6. Mean daily discharges in the east and west channels of Goose Creek over the period April 29-May 20, 1977.

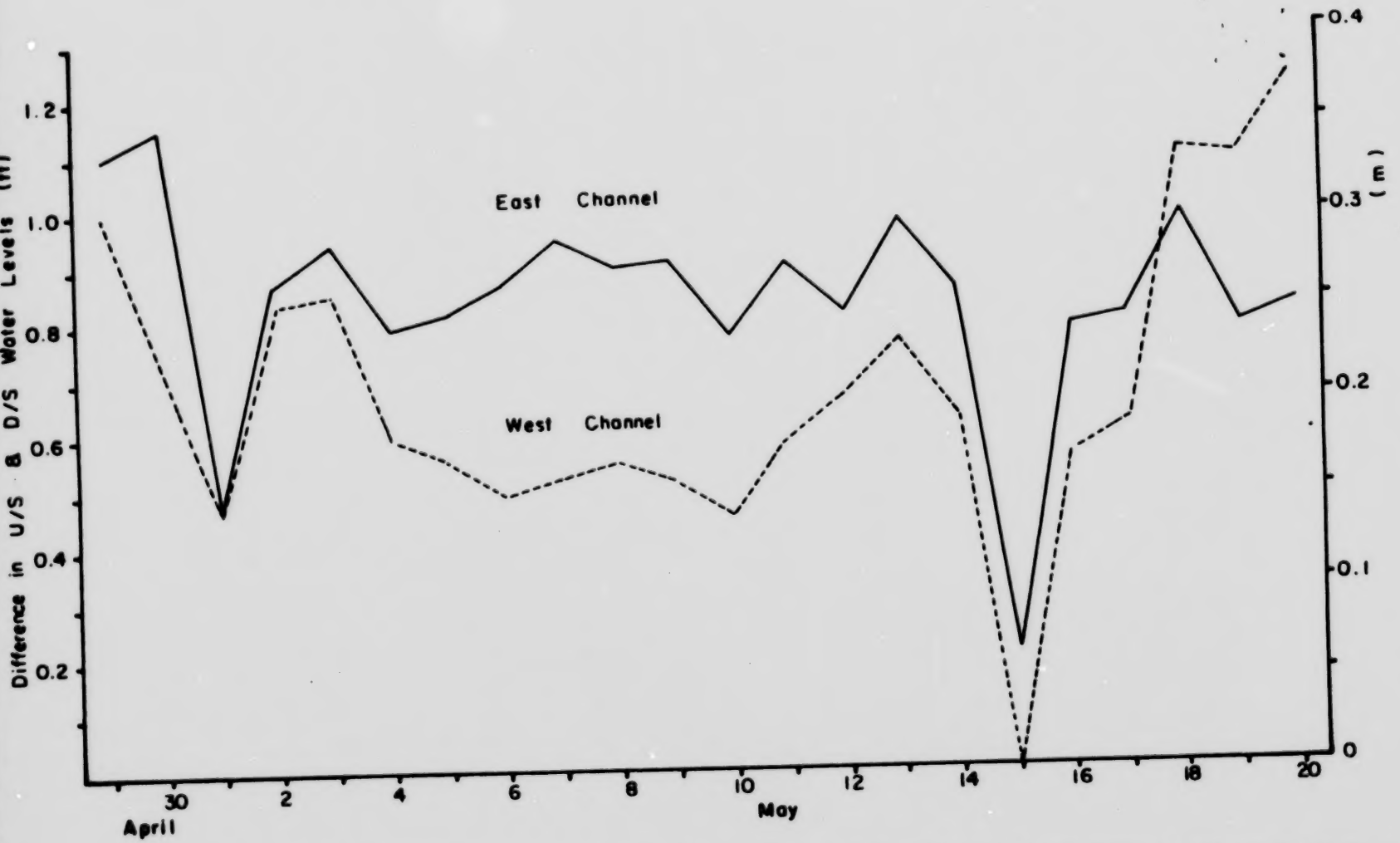

Figure 7. Daily differences between water levels upstream and downstream of the Goose Creek crossing over the period April 29-May 20, 1977.

The daily average velocities and the lowest daily velocities through all five culverts in the Goose Creek crossing were determined (Figs. 8 to 12). No velocities were recorded on May 14 and 15 in culverts 4 and 5 (Figs. 11 and 12) since flows in the west channel stopped or reversed during that time. Highest velocities were recorded in culvert 2 in the east channel (Fig. 9) and lowest velocities generally were observed in culvert 5 in the west channel (Fig. 12). The lowest velocity recorded on any given day occurred on May 15 in culvert 1; velocity at this time was 0.44 m s^{-1} (1.44 fps). Daily fluctuations in velocity were closely similar in culverts 1 to 3. Velocities dropped significantly on May 1, then rose and remained relatively constant until they dropped again on May 15. They increased again on May 16 and thereafter remained at about the same levels observed over the period May 2 to 14. Velocities in culverts 4 and 5 tended to drop off more sharply than those in culverts 1 to 3 after May 2. Velocities in culvert 4 differed from those in culvert 5 in that a sharp decline was noted in culvert 4 on May 6. The reason for this sudden drop in velocity is not known. It may have been due to debris or a small ice jam within the culvert which could not be observed by the monitoring crew. Lower culvert velocities (less than 0.91 m s^{-1} or 3 fps) occurred more frequently in west channel than in the east channel. Velocities observed in culvert 4 and/or 5 dropped below 0.91 m s^{-1} on 19 days while velocities less than 0.91 m s^{-1} were noted in culverts 1-3 only on seven days (Appendix A-1).

Velocities near the bottom of the culverts were generally lower than surface velocities. The differences between "surface" and and "bottom" velocities were greater for culverts 1-3 than those for

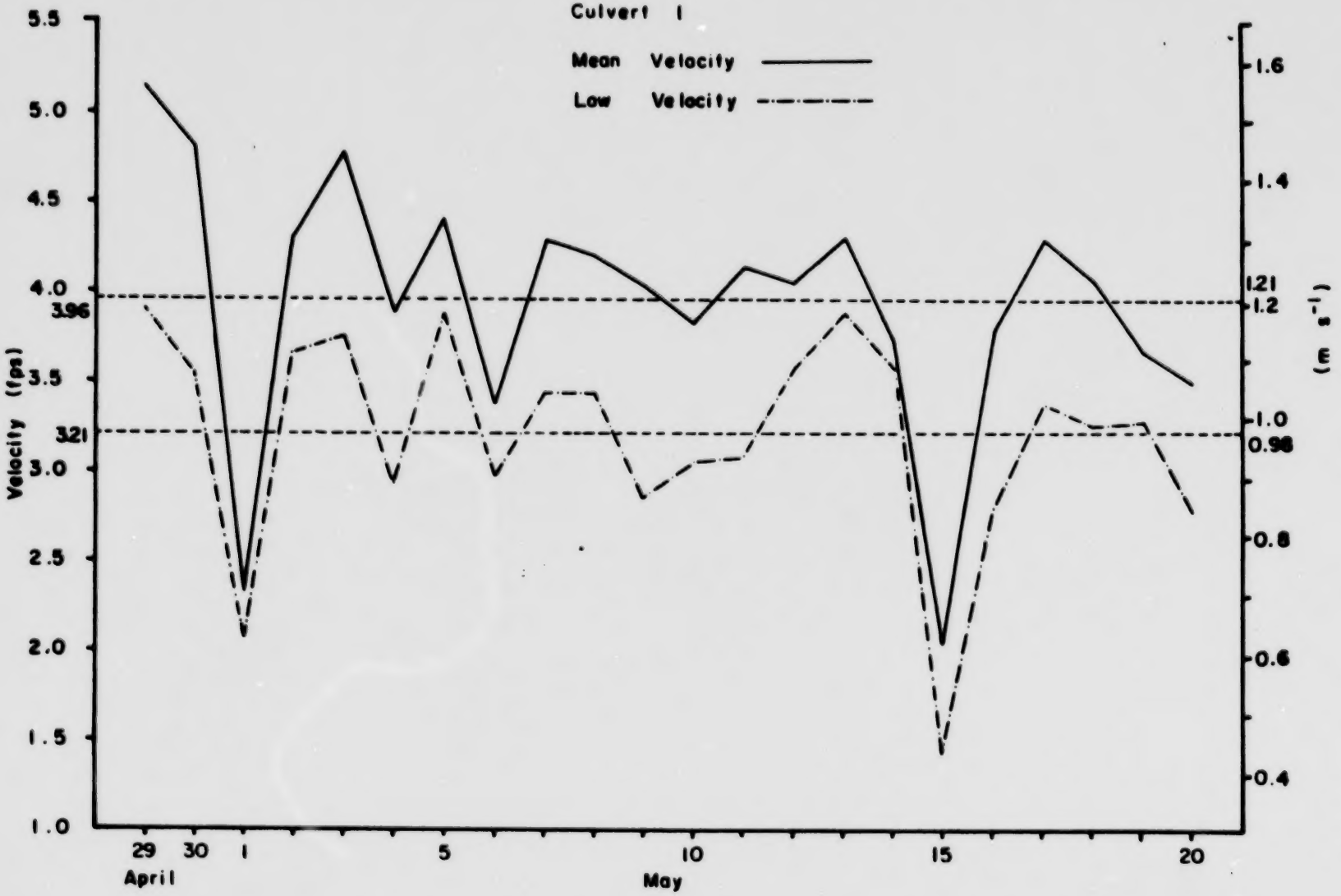

Figure 8. Daily mean and low water velocities in culvert 1 over the period April 29-May 20, 1977.

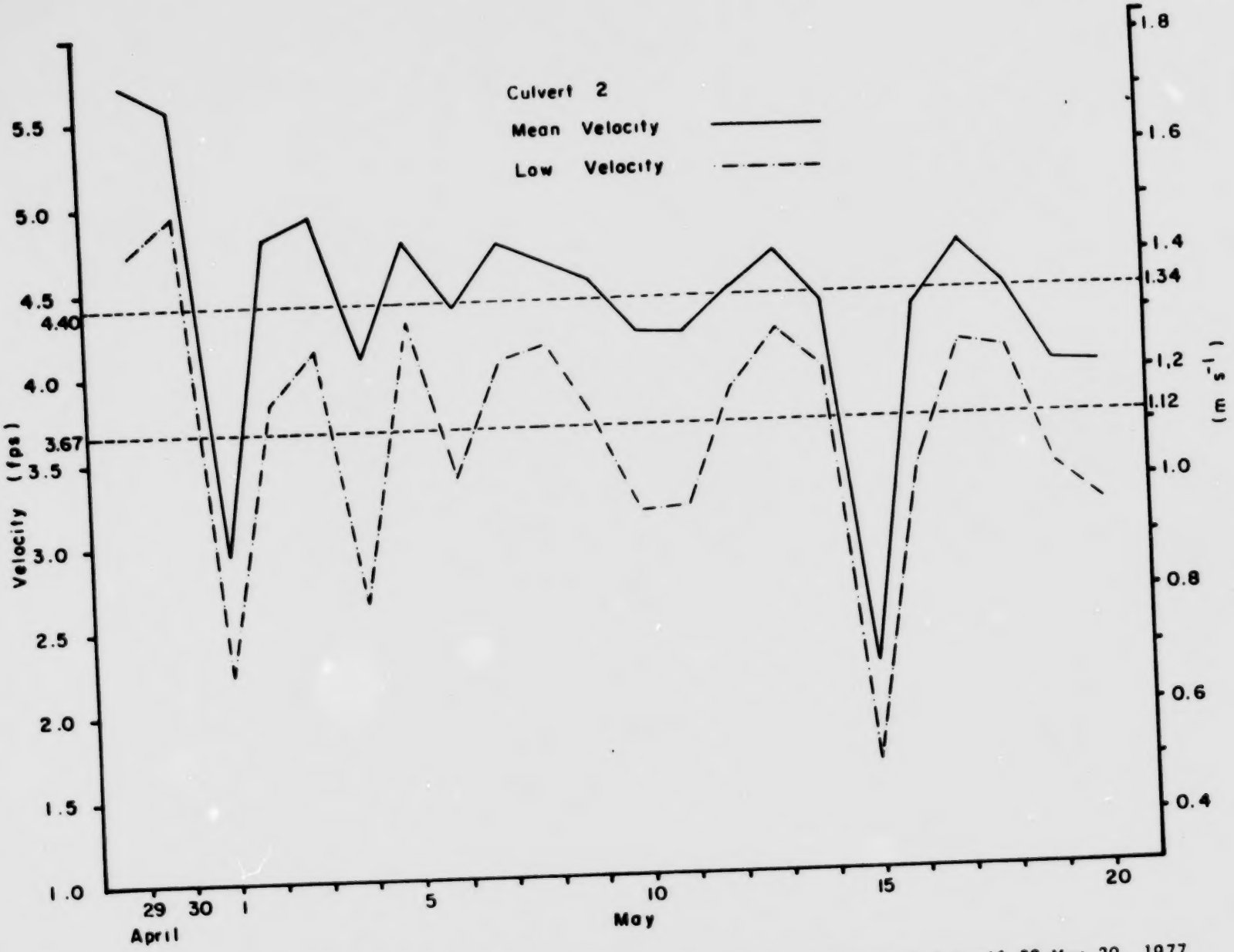

Figure 9. Daily mean and low water velocities in culvert 2 over the period April 29-May 20, 1977.

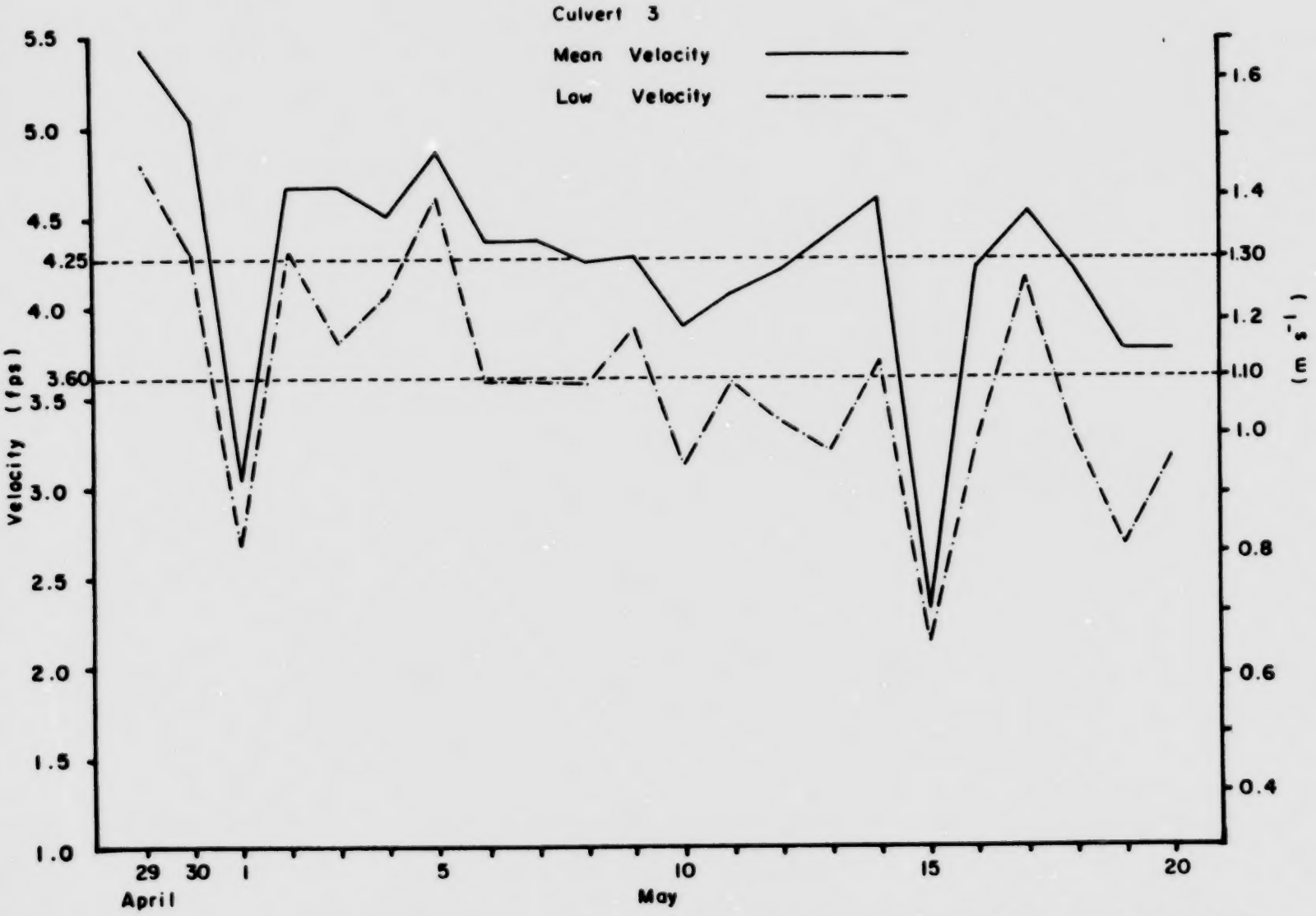

Figure 10. Daily mean and low water velocities in culvert 3 over the period April 29-May 20, 1977.

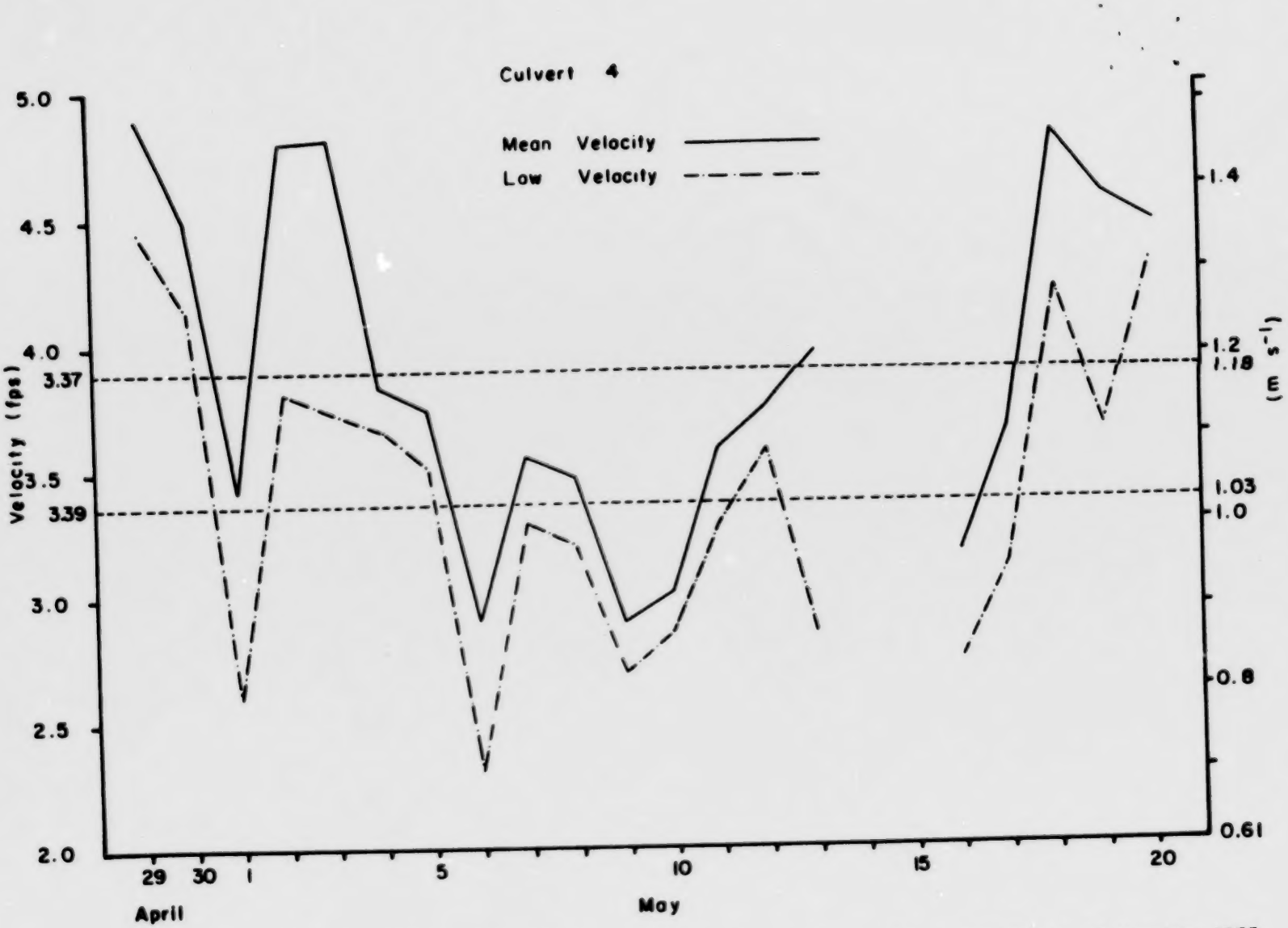

Figure 11. Daily mean and low water velocities in culvert 4 over the period April 29-May 20, 1977.

Figure 11. Daily mean and low water ...

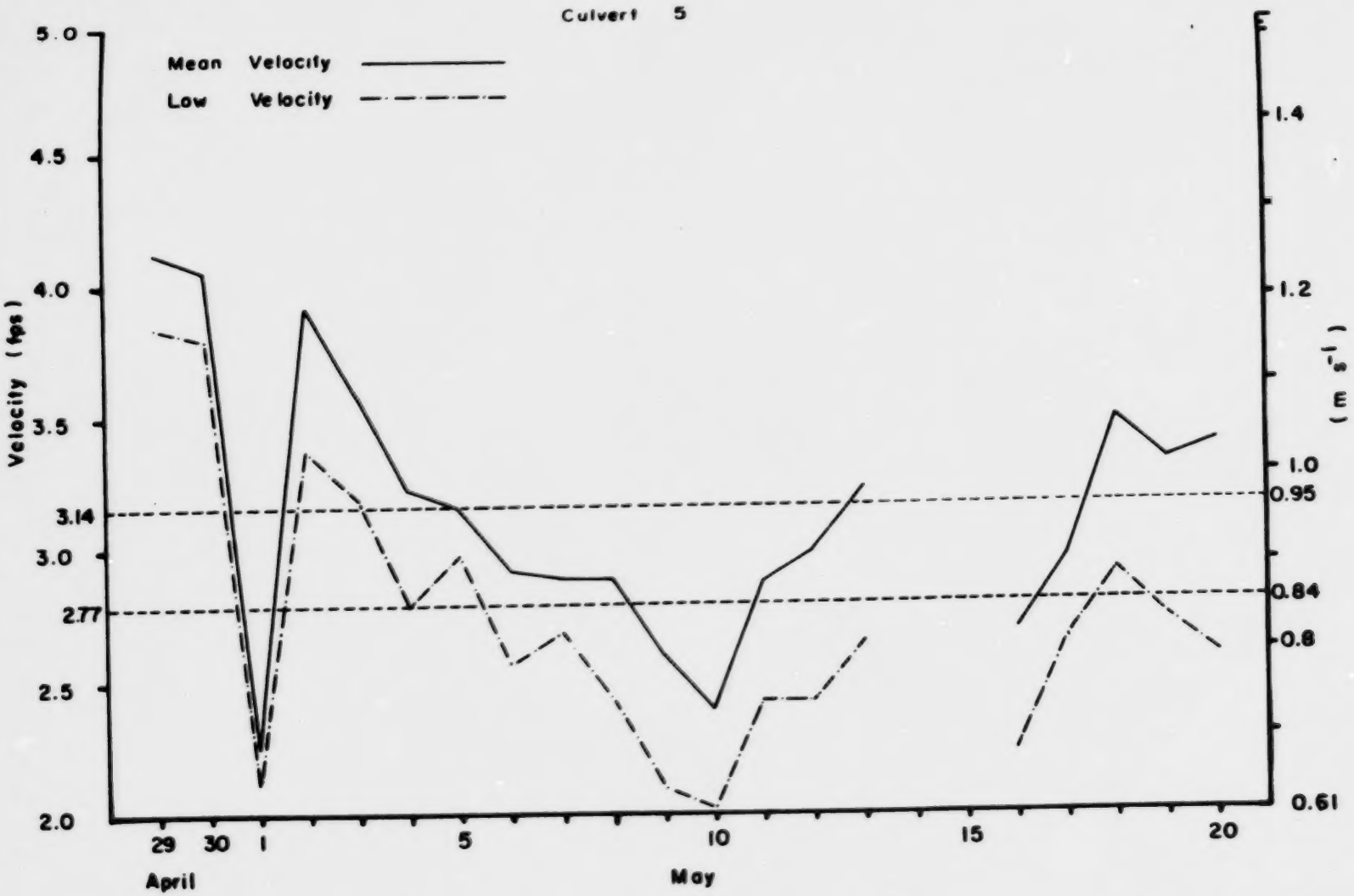

Figure 12. Daily mean and low water velocities in culvert 5 over the period April 29-May 20, 1977.

culverts 4 and 5. (Appendix A-2). The greatest mean difference between "surface" and "bottom" velocities was 0.28 m s^{-1} (0.93 fps). This was observed in culvert 1. A sufficient number of points across the ends of the culverts were not measured to adequately examine velocity profiles.

Velocities were measured on only one occasion (April 29) at the upstream end of one culvert (culvert 1). Velocities were measured at approximately 0.3 m below the water surface and 0.3 m above the culvert bottom. Velocities at these two points were 2.41 m s^{-1} (7.92 fps) and 2.44 m s^{-1} (8.02 fps), respectively. The average water velocity in culvert 1 at the downstream end at this time was 1.56 m s^{-1} (5.12 fps). Water level at the upstream end of the culvert was 21 cm higher than the water level at the downstream end. Water velocities at the upstream ends of the culverts were probably higher than those recorded at the downstream ends due to drawdown effects. Upstream water levels in all culverts, except culvert 2, were higher than the downstream water levels (Appendix A-3). In culvert 2, water levels at the upstream and downstream ends of the culverts were approximately equal. This might explain why velocities through culvert 2 were, on average, higher than velocities through the other four culverts.

Data collected in the hydrometric monitoring can be used to obtain some estimate of water velocities through the Goose Creek culverts for various stream discharges. The relationships between discharges and velocities in the three east channel culverts were very similar (Fig. 13). Fig. 14 illustrates the relationship between the combined daily average water velocities through the three culverts in the east channel and the discharges in the same channel. The curve

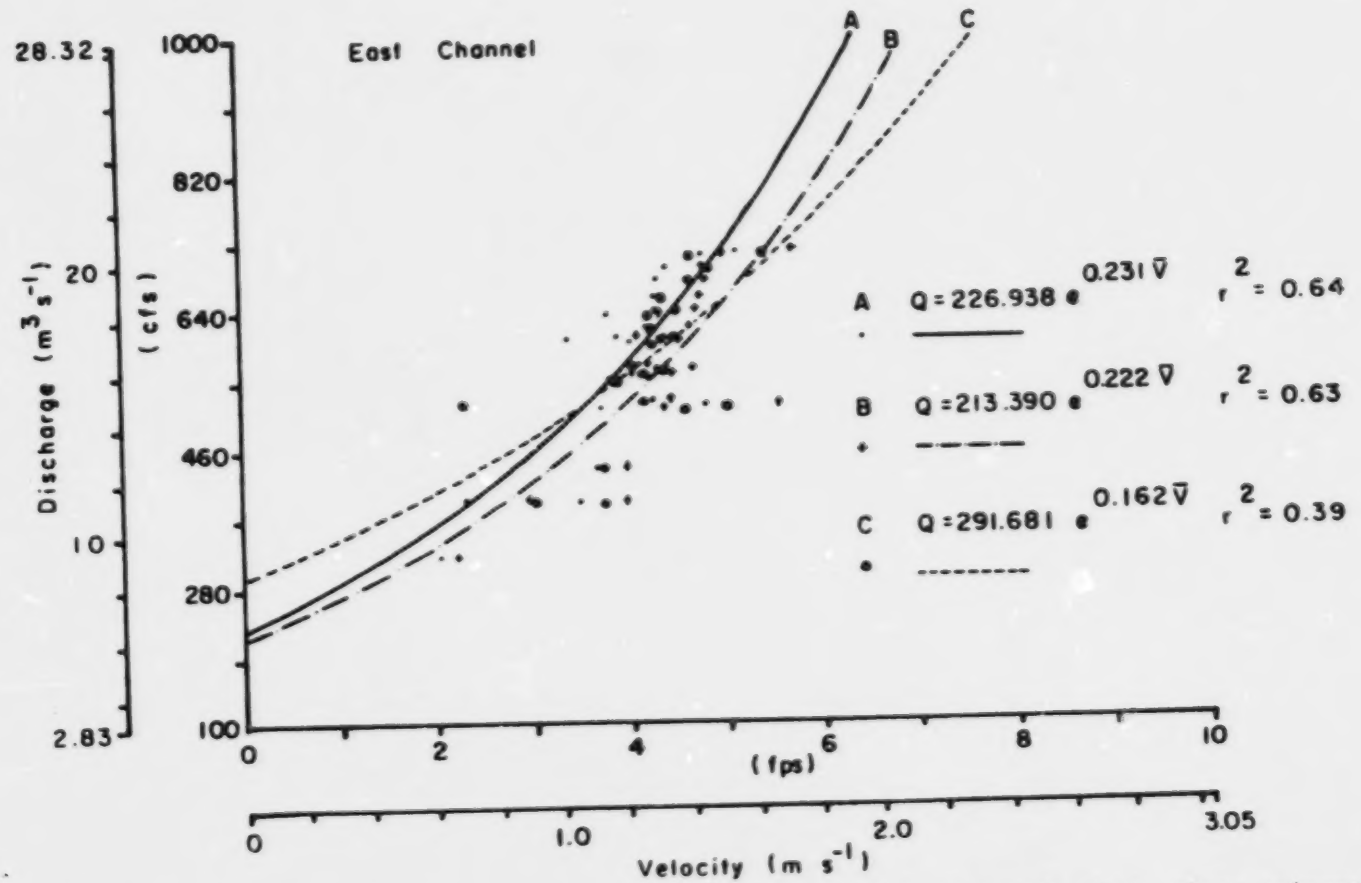

Figure 13. Relationships between the average water velocities in each of the three culverts in the east channel and discharges in the east channel.

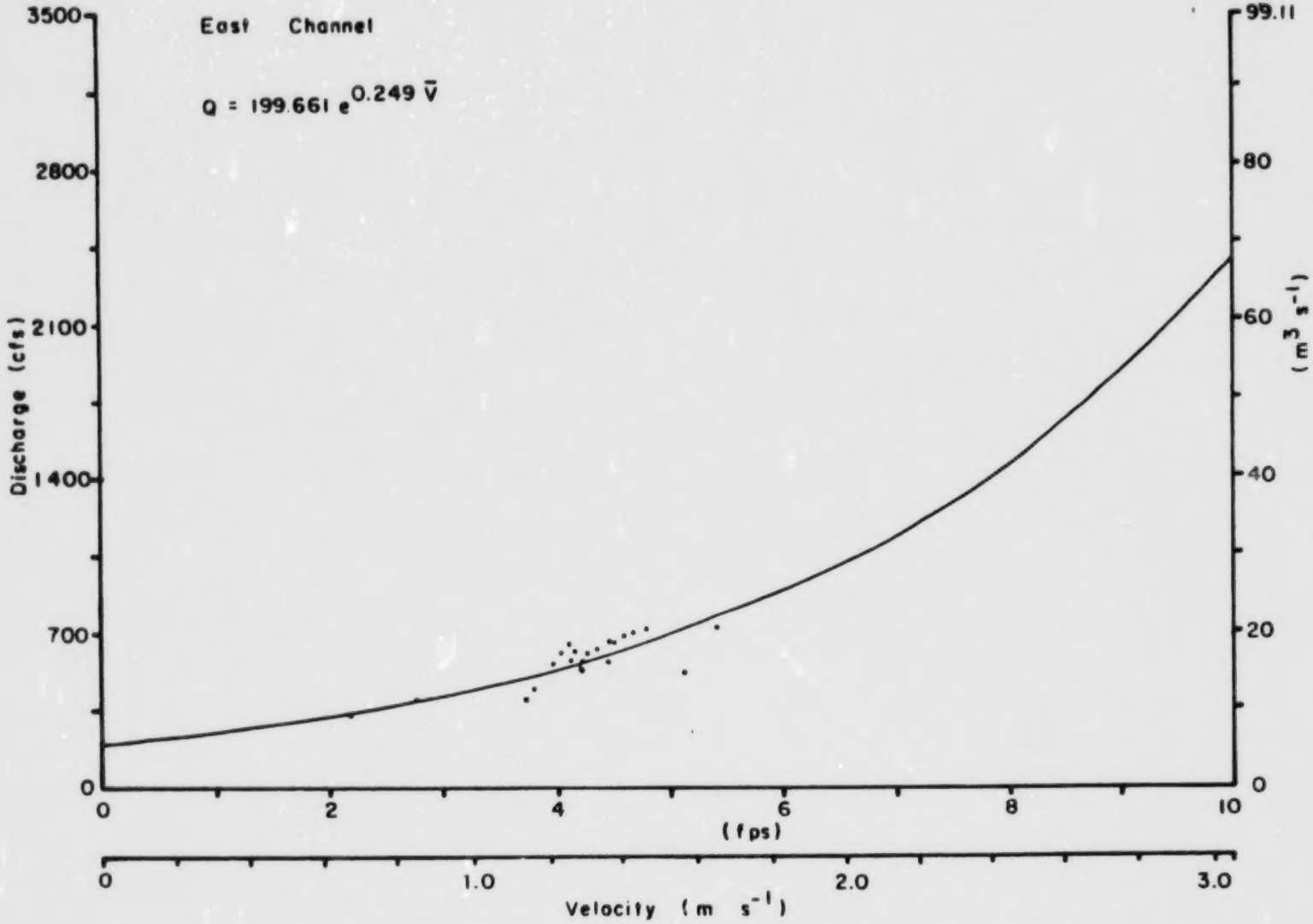

Figure 14. Relationship between the average water velocities in the three culverts in the east channel and discharges in the east channel.

for the combined data ($Q = 199.661\ e^{0.249\bar{V}}$) accounted for 68 per cent of the variability ($r^2 = 0.68$). This correlation was slightly better than that obtained for individual culverts.

Curvilinear regression analysis of velocities and discharges for the west channel culverts showed a different relationship than that observed in the east channel (Fig. 15). At low discharges, velocities in the west channel culverts were less than velocities in the east channel culverts. Fig. 16 shows the relationship between the combined velocities through the west channel culverts and the west channel discharges; the curve equation is $Q = 132.377\ e^{0.227\bar{V}}$ and $r^2 = 0.62$.

The correlation between discharges and water velocities within the culverts was not improved by combining data for the east and west channels. In this case, the equation ($Q = 393.124e^{0.207\bar{V}}$) accounted for only 43.5 per cent ($r^2 = 0.435$) of the variability in the data. (Fig. 17). Using the above equations, water velocities through the Goose Creek culverts were estimated at discharge rates equivalent to the estimated 50-year flood, 25-year flood and the 7-day delay discharges (Table 3). Water velocities estimated for the west channel culverts were about 0.91 m s^{-1} (3 fps) higher than those for the east channel culverts at the given discharge rates. This could be expected since the east channel has an additional culvert and can therefore accommodate a greater discharge with a smaller increase in culvert water velocity. Velocities estimated for culverts in both channels were less than the estimates obtained for the separate channels. These estimates (both channels combined)are questionable because of the poor correlation (44%) obtained.

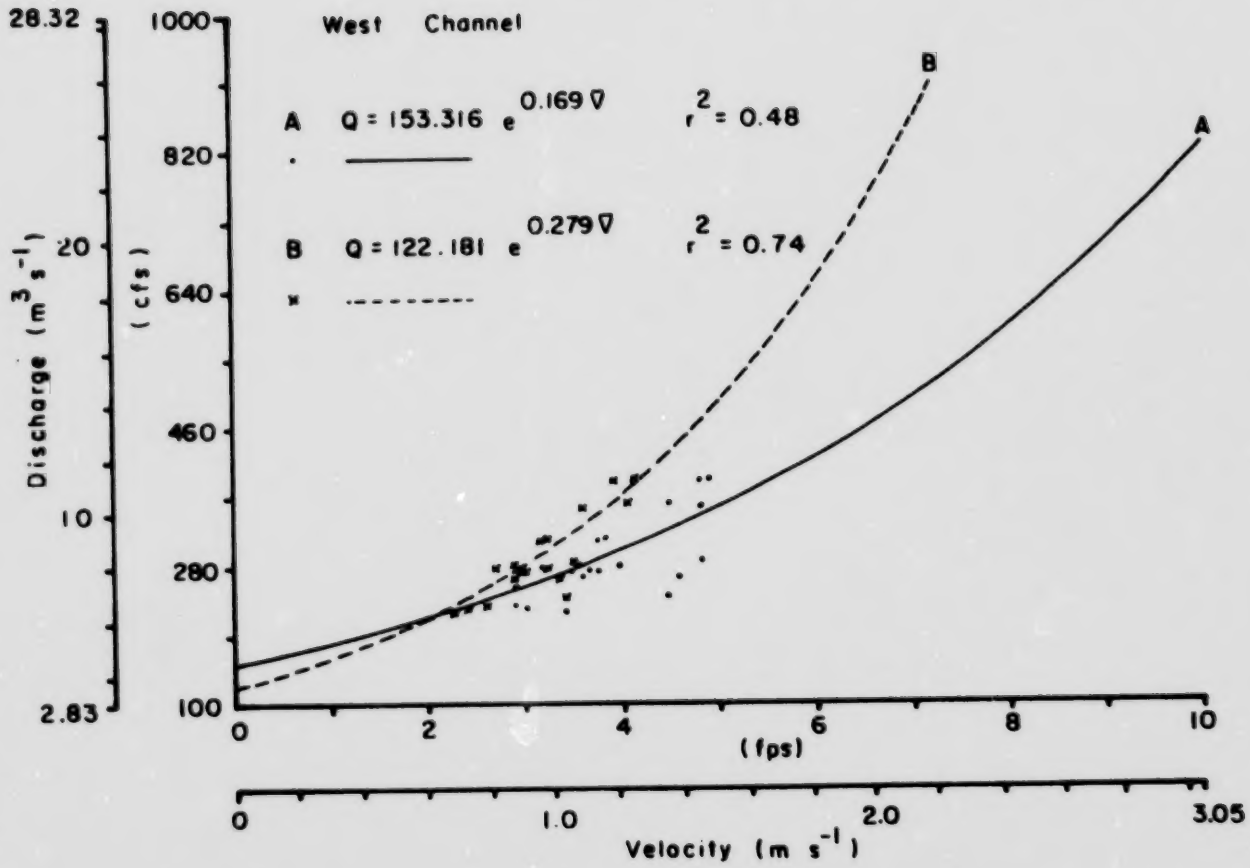

Figure 15. Relationships between the average water velocities in each of the two culverts in the west channel and discharges from the west channel.

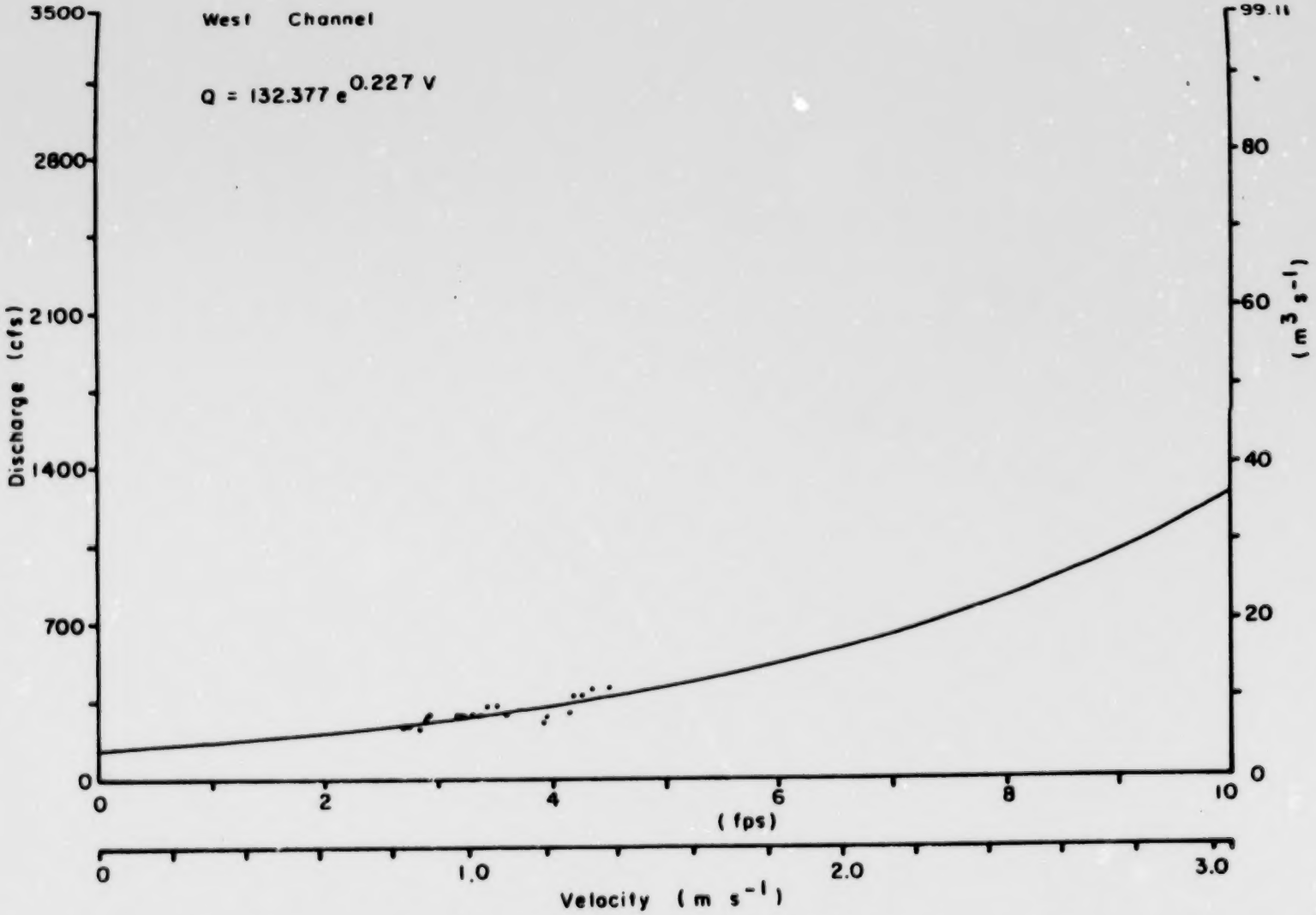

Figure 16. Relationship between the average water velocities in the two west channel culverts and discharges in the west channel.

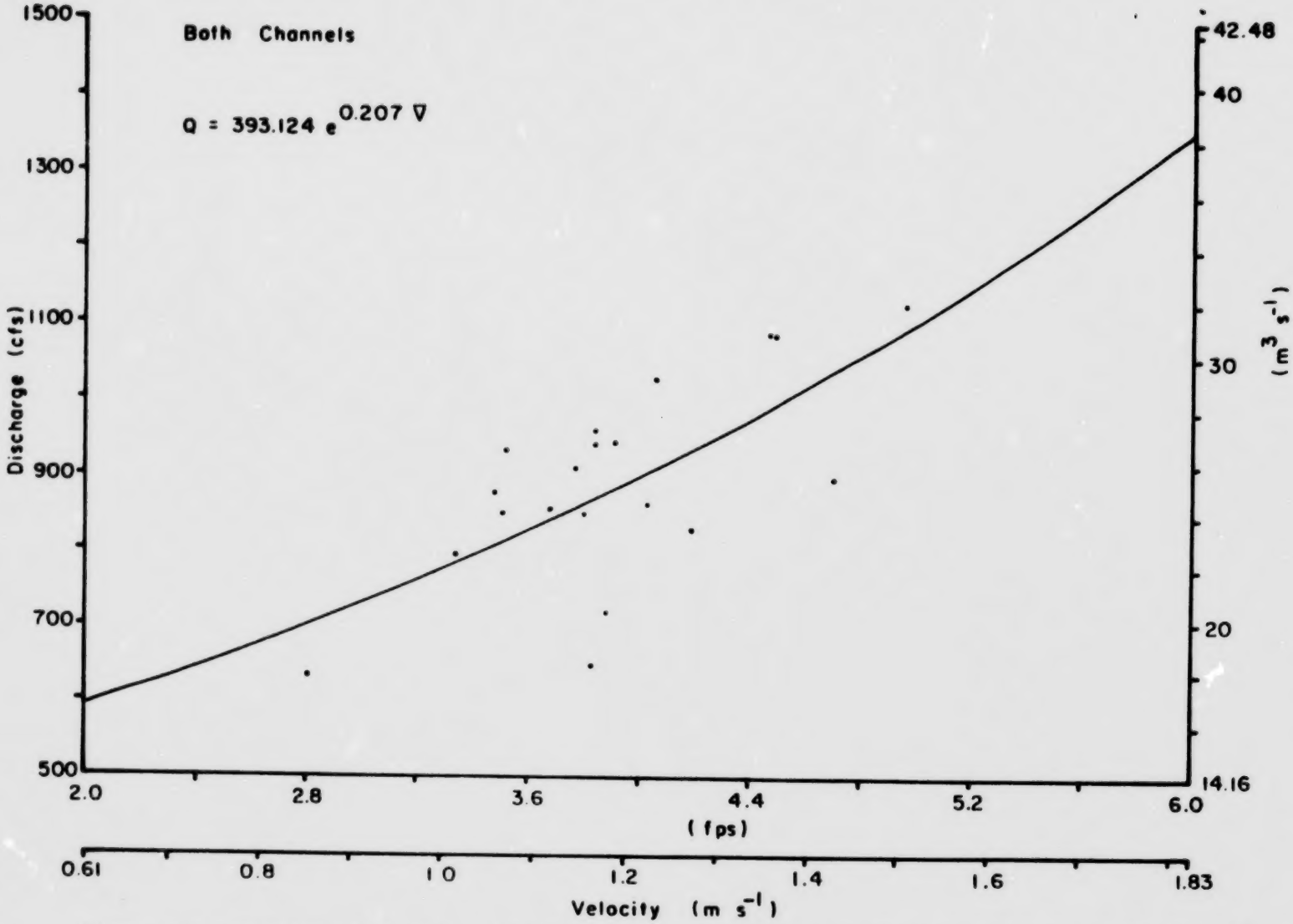

Figure 17. Relationship between the average water velocities in the five culverts in the Goose Creek crossing and the discharges in Goose Creek.

Table 3. Estimated water velocities in Goose Creek culverts from "best-fit" equations derived from field observations.

Discharge ($m^3 s^{-1}$)	Estimated water velocities ($m s^{-1}$)		
	East Channel	West Channel	Both Channels
	Culverts 1-3	Culverts 4-5	Culverts 1-5
92.0 (Q_{50})	3.41	4.30	3.10
79.2 (Q_{25})	3.23	4.11	2.90
77.8	3.20	4.08	2.87
72.2	3.11	3.96	2.74
56.6	2.80	3.69	2.41
49.0 (7-day delay)	2.65	3.44	2.19
28.3	1.98	2.71	1.37
14.2	1.13	1.80	0.37

Comparing results presented in Table 3 with theoretical estimates made by Stratton (1976) (Table 1), velocities as estimated from field measurements appear in most cases considerably higher than the theoretical estimates. For example, the empirical estimate of water velocities at Q_{25} (79.2 $m^3 s^{-1}$) ranged between 2.90 and 4.11 m s^{-1} (9.5-13.5 fps). Stratton (1976) estimated water velocities in the culverts would be 2.04 m s^{-1} (6.7 fps) at a discharge rate of 77.8 $m^3 s^{-1}$ (Table 1). Only the velocities estimated from the combined channel data for discharges at 28.3 and 14.2 $m^3 s^{-1}$ and the east channel culverts at 14.2 $m^3 s^{-1}$ were lower than Stratton's estimates.

A relationship was found between daily water levels in the east channel culverts and discharges (Fig. 18). This relationship was not found for the west channel. The absence of such a relationship for the west channel may be due to the greater effect of backwater from the Churchill River. The equation in Fig. 18 accounted for 63 per cent of the variability ($r^2 = 0.631$). Based upon the equation $Y = 0.190 Q^{0.512}$, culverts in the east channel would be full when the channel discharge was approximately 51.2 $m^3 s^{-1}$. Therefore, discharges of 56.6 $m^3 s^{-1}$ or greater in the east channel would inundate that portion of the road crossing. Stratton (1976) estimated that all culverts in Goose Creek would flow full or nearly full when discharges reached 72.2 $m^3 s^{-1}$ (Table 1). In this case, each culvert would discharge 14.4 $m^3 s^{-1}$. Based upon estimates obtained for the east channel culverts, each of the three culverts could accommodate approximately 17 $m^3 s^{-1}$. If this capacity applied to the other two culverts in the west channel, then the Goose Creek culverts could handle a discharge of about 85 $m^3 s^{-1}$

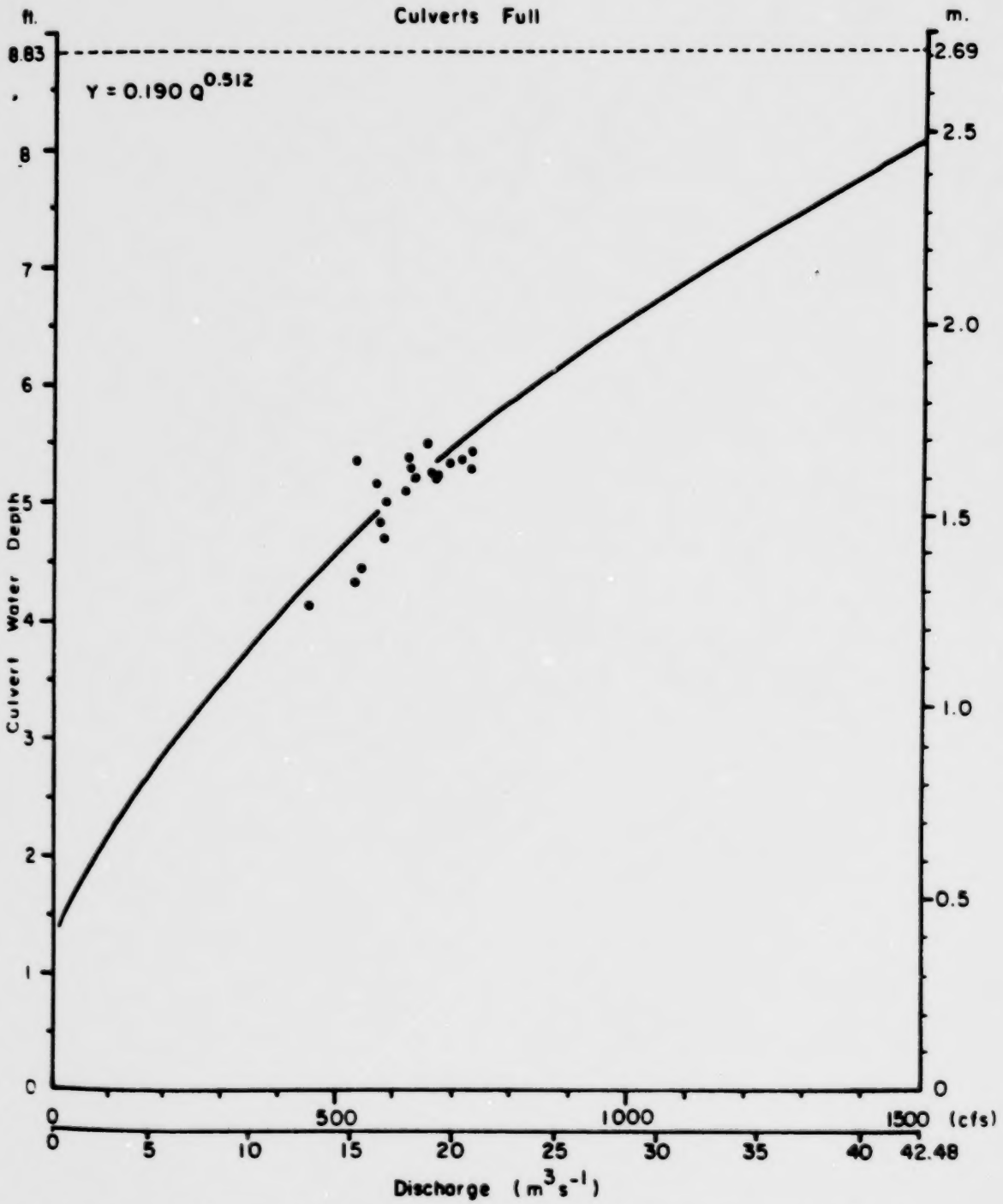

Figure 18. Relationship between water levels in the three east channel culverts and discharges in the east channel.

or almost the total 50-year flood discharge. The Goose Creek crossing could only accommodate this discharge provided there were no backwater effects from the Churchill River. Since the backwater effect appears to be most pronounced in the west channel, flows could be diverted to the east channel and could exceed the capacity of the culverts.

Evans and Johnston (1972) presents data on water velocities and water depths in various types and sizes of culverts set at various slopes and at various discharges. Data are presented for a 12 foot 8 inch x 8 foot 1 inch (3.89 x 2.46 m) corrugated pipe arch culvert. This is approximately the same size and type of culvert used in the Goose Creek crossing. Evans and Johnston's (1972) data for water depth and discharge closely approximates the Goose Creek data (Fig. 18) if the curve for a one per cent slope is examined. Water depths derived from Evans and Johnston's (1972) data are about 15 cm less than the water depths determined from Fig. 18 for a given discharge rate. Given a discharge of 11.32 $m^3 s^{-1}$ and a slope of one per cent, Evans and Johnston (1972) show a culvert velocity of approximately 3.35 m s^{-1} (11 fps). Extrapolating these conditions to the Goose Creek situation, a discharge of 56.6 $m^3 s^{-1}$ (11.32 x 5 culverts) would produce average water velocities in each culvert of approximately 3.35 $m^3 s^{-1}$. This estimate differs greatly from velocities estimated from empirical results. If the discharge in the east channel of Goose Creek was 33.96 $m^3 s^{-1}$, the average water velocity through the three culverts would be 2.19 m s^{-1} or 7.2 fps (Fig. 14). With a discharge of 22.64 $m^3 s^{-1}$ the mean velocities through the two west channel culverts would be about 2.44 m s^{-1} or 8.0 fps

(Fig. 16). The slower velocities observed in the Goose Creek culverts may be due to the culverts being set at a slope smaller than one per cent.

Biological Monitoring

Monitoring of fish movements in the Goose Creek crossing area began well after breakup on the creek. Breakup in 1977 probably occurred much earlier than usual. The early breakup is reflected in air temperature records from the Churchill Airport. In 1977, air temperatures during mid-April were considerably above long term average temperatures (Fig. 19a). Comparison with temperatures in previous years (1970-1974) indicate that April, 1977 was an unusually warm month (Table 4). Although surface water temperatures in Goose Creek were not recorded until May 3, the pattern of surface water temperatures corresponded with that of air temperatures (Fig. 19b). Low temperatures during the first few days in May resulted in Goose Creek freezing over lightly. Water temperatures before this cold spell were probably similar to those observed after May 6.

The species and numbers of fish caught in hoop nets set downstream of the culverts in the east and west channels and that were tagged and released below the culverts are shown in Tables 5 and 6. Three of the six species caught were believed to be moving into Goose Creek to spawn; these were Arctic grayling, longnose suckers (Catostomus catostomus) and northern pike. Burbot (Lota lota) and perhaps whitefish (Coregonus clupeaformis and Prosopium cylindraecium) appeared to be moving into the creek to feed. It should be noted that many more burbot

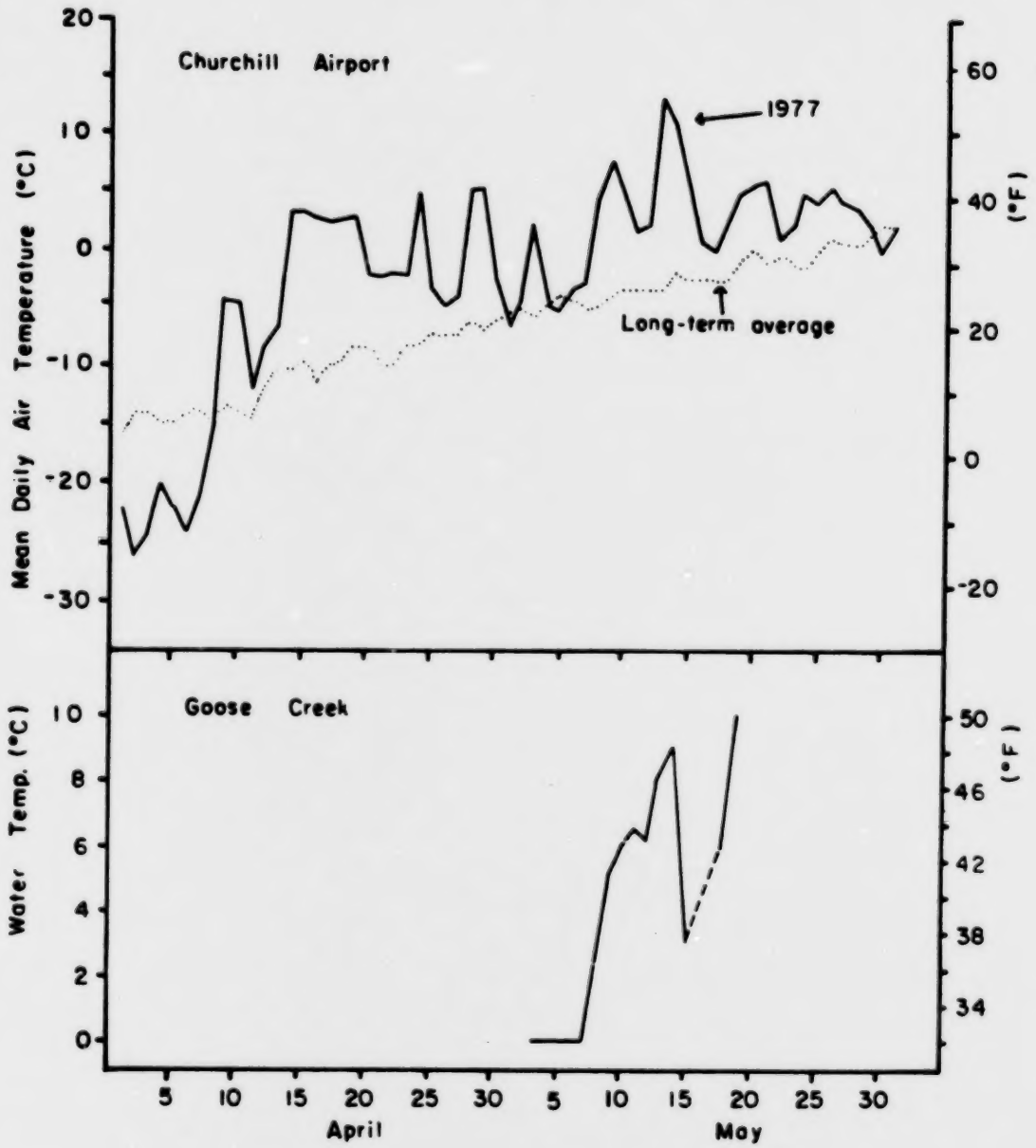

Figure 19. (a) Mean daily air temperatures recorded at Churchill Airport during April and May, 1977, and the long-term average daily air temperatures.
(b) Daily surface water temperatures at Goose Creek, May 3 to 18, 1977.

Table 4. Deviation in April and May air temperatures (F) at Churchill Airport for 1977 and 1970-1974 from the long term average.

	Deviation from long term average monthly air temperature	
Year	April	May
1977	+7.4	+7.5
1974	-0.8	+0.2
1973	+0.6	+6.4
1972	-	+2.5
1971	+1.0	+7.5
1970	-1.5	-2.9
Long Term Average	12.2	28.0

Table 5. Number of fish of each species tagged each day in the east channel of Goose Creek. Except for pike tagged on April 27, the fish were caught in Hoop Net 1 set immediately downstream of Culvert 1.

Date	No. of fish tagged			
	Arctic Grayling	Longnose Sucker	Burbot	Northern Pike
Apr. 27	-	-	-	4*
28	5	4	3	32
29	3	58	3	14
30	2	51	7	9
May 1	-	-	-	-
2	-	-	-	-
3	-	10	3	-
4	-	38	1	-
5	-	57	6	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	1	7	1	-
12	-	1	-	-
Total	11	226	24	59+

* Caught by angling
\+ One fish not measured

Table 6. Number of fish of each species tagged each day in the west channel of Goose Creek. Fish were caught in Hoop Net 2 set immediately downstream of Culvert 4.

Date	No. of fish tagged				
	Arctic Grayling	Longnose Sucker	Burbot	Northern Pike	Whitefish+
May 7	1	229	34	22	-
8	-	109	-	16	-
9	-	126	-	23	-
10	-	19	13	28	1
11	1	5	-	9	-
12	-	6	14	19	1
13	-	4	17	17	2
14	-	1	2	5	-
Totals	2	499	80*	139	4

* 7 fish not measured
\+ May include both lake and round whitefish

were caught than the number tagged. All burbot were not tagged because of a shortage of tags. Unfortunately, those burbot which were not tagged were not otherwise marked or tallied. It should also be noted that two species of whitefish (lake and round whitefish) were caught, but these were not distinguished until the latter part of the monitoring period.

Excepting the burbot that were not tallied, 1044 fish were captured below the Goose Creek culverts. Most of these fish (69.3%) were caught in the west channel and during the last week of downstream netting (May 7-14). Churchill residents claimed that spring runs of fish into Goose Creek were heaviest in the west channel. The movement of large numbers of fish into the west channel of Goose Creek might be accounted for by the possibility that most of the fish going into the creek came from the upstream portion of the Churchill River. These fish would encounter the west channel of Goose Creek first and therefore move into that channel. The quantity of fish in the Churchill River downstream of the Goose Creek confluence would be limited because of tidal and saltwater influences from Hudson Bay. Another possibility may be that because of the lower discharges and slower currents, fish are better able to swim in the west channel.

The mean lengths of northern pike, longnose suckers and burbot (Figs. 20-22) caught in the east channel were greater than those of fish captured in the west channel (Table 7). Although these differences were not statistically significant, they suggest that the average size of fish in the two channels may have been influenced, at least in part, by water velocities. Water velocities through the east channel culverts were greater than in the west channel culverts. Presumably water velocities in the stream channels below the culverts were also

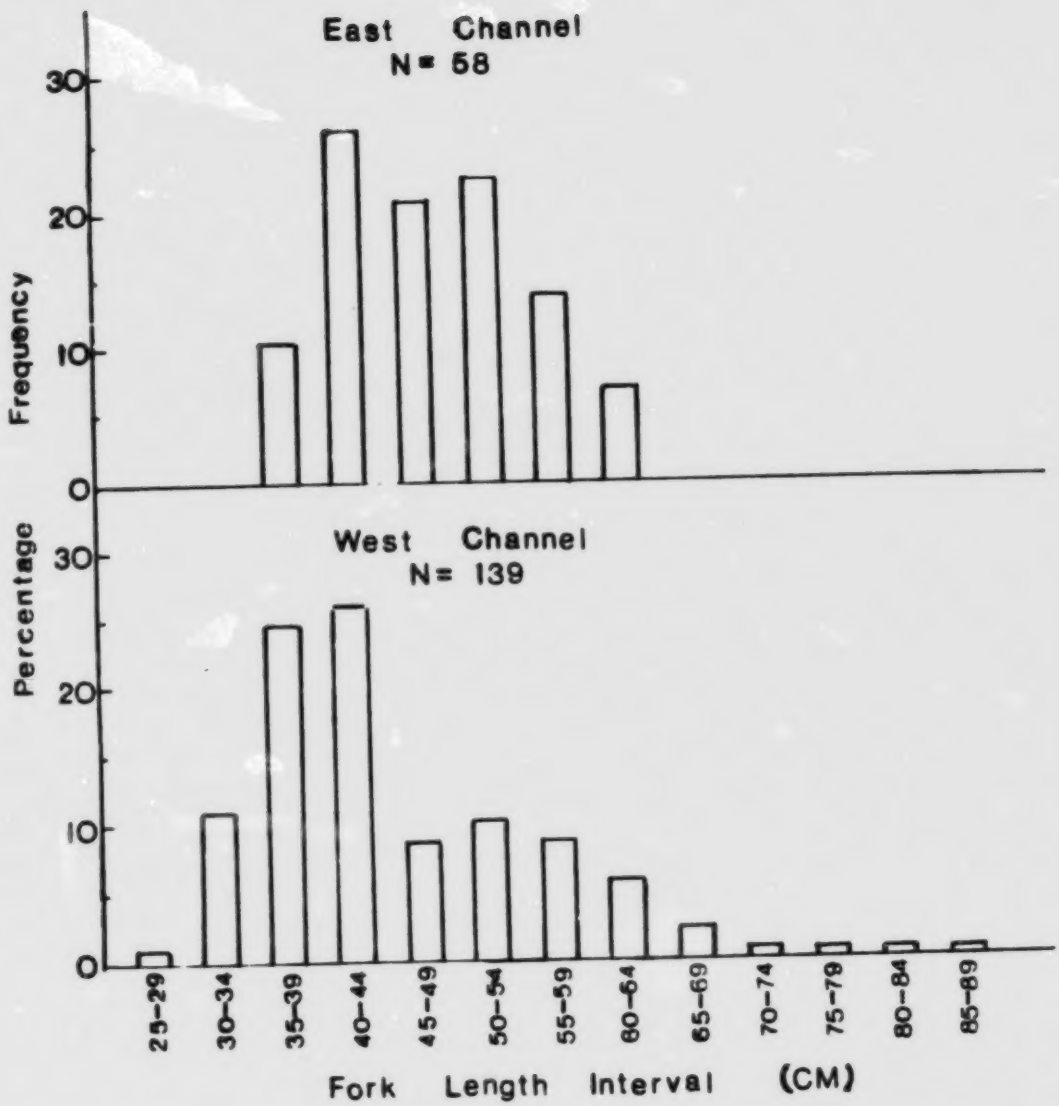

Figure 20. Length frequency distribution of northern pike caught in hoop nets set below the culverts in the east and west channels of Goose Creek.

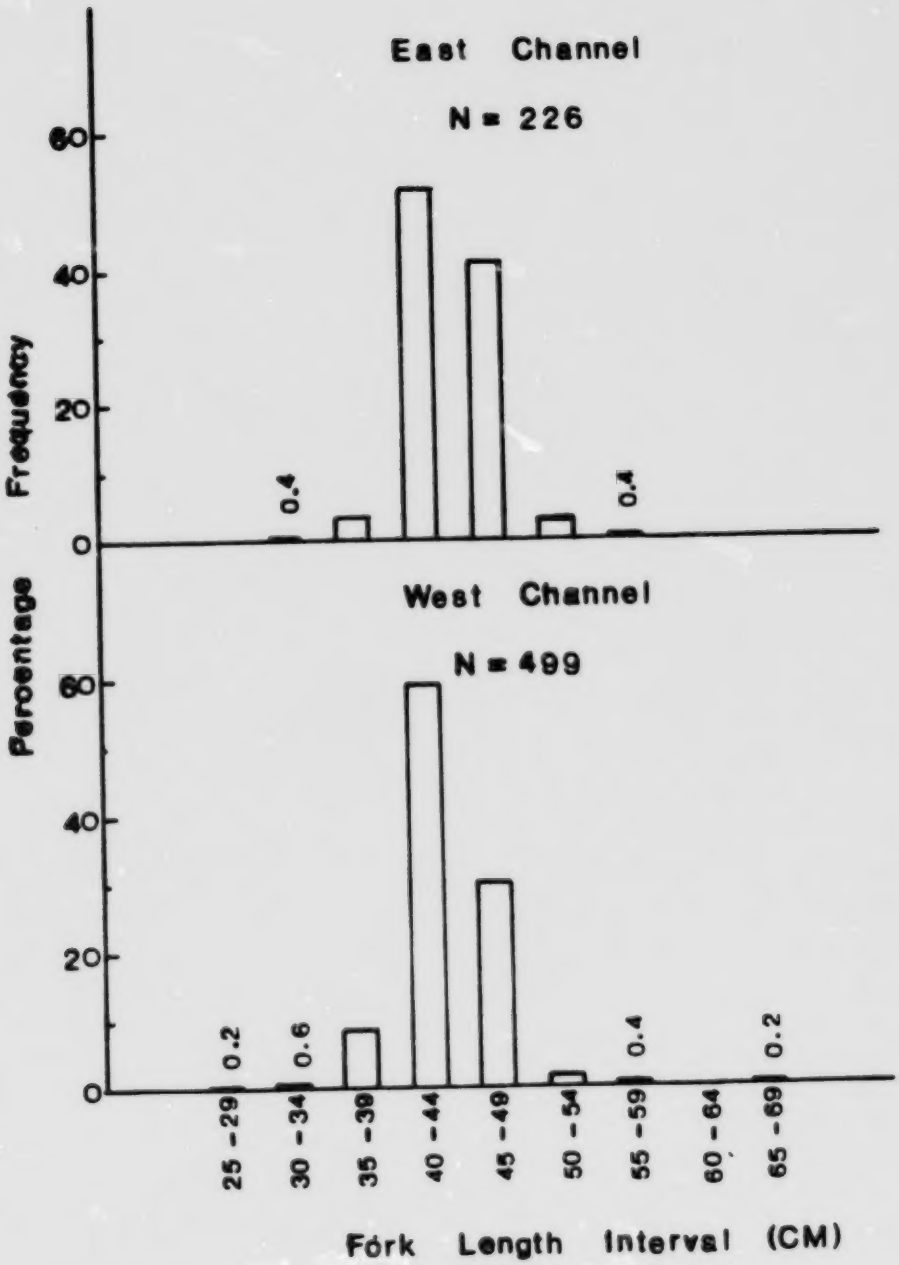

Figure 21. Length frequency distribution of longnose suckers caught in hoop nets set below the culverts in the east and west channels of Goose Creek.

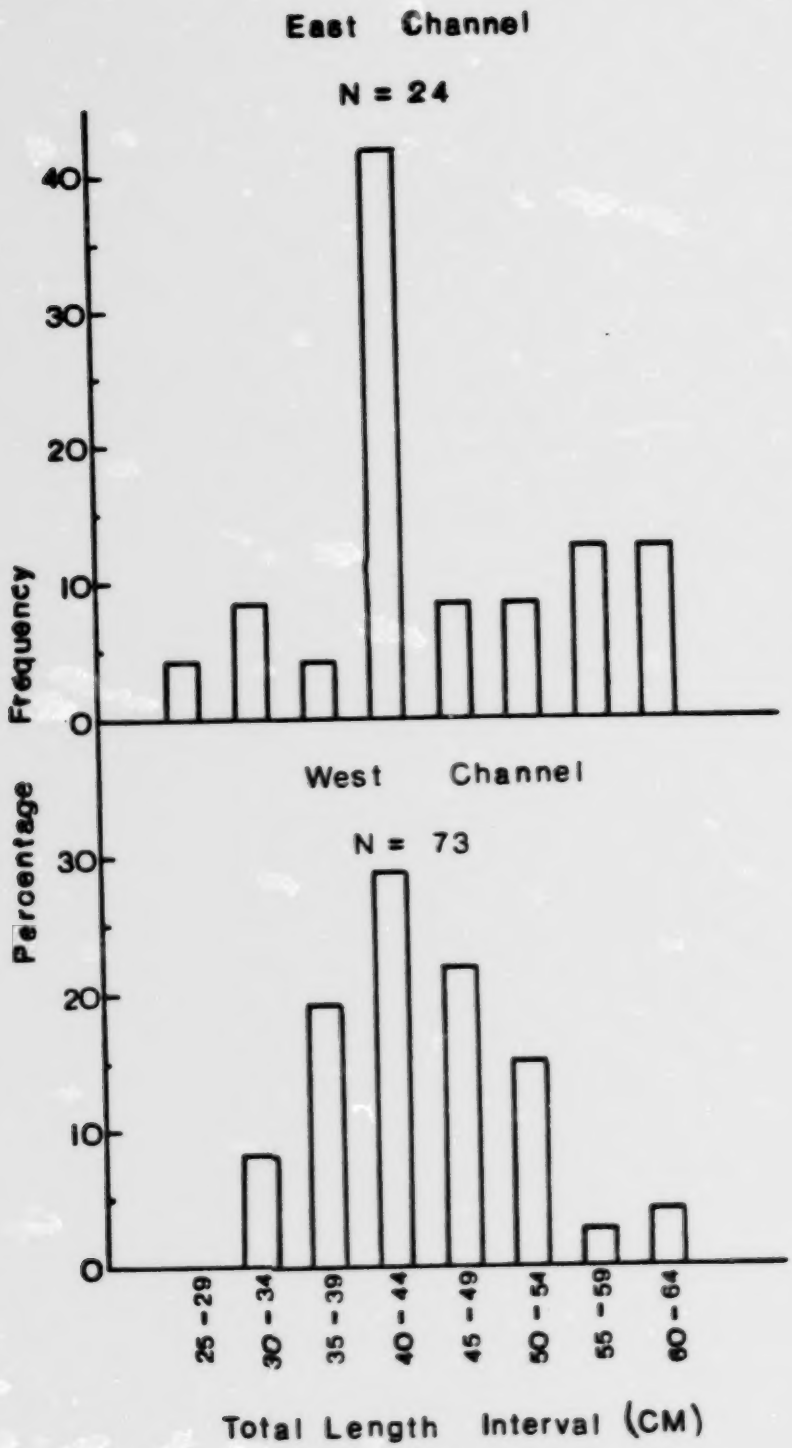

Figure 22. Length frequency distribution of burbot caught in hoop nets set below the culverts in the east and west channels of Goose Creek.

Table 7. Mean length of northern pike, longnose suckers and burbot caught in hoop nets from the east and west channels of Goose Creek.

Species	Mean length in cm	
	East Channel	West Channel
N. Pike	48.2	45.1
Longnose Sucker	44.2	43.3
Burbot	46.0	44.1

slightly higher in the east channel than in the west channel. If this was the case, then the smaller fish would have been excluded from the east channel. This explanation does not account for the larger pike and longnose suckers which were caught in the west channel (Figs. 20 and 21).

Catches of Arctic grayling and whitefishes in the hoop nets set below the culverts were not large enough to draw any definite conclusions on movements of the two species. Only 13 grayling were caught in the hoop nets; 11 of these were caught in the hoop net set below culvert 1 in the east channel (Table 8). Four whitefish were caught in the west channel.

There is some indication of diel differences in the movements of pike and suckers into Goose Creek. Pike catches in the west channel were greater in the morning than in the afternoon (Table 9). The morning catches probably resulted from pike moving during the period of darkness and therefore represent nocturnal movements. (Nocturnal movements would be of some advantage since during spring runoff, stream flows usually decline in the evening because temperatures decrease and retard melting and hence discharges). Nocturnal and diurnal movements of pike in the east channel appeared to be equal. However, relatively few pike were caught in the east channel and these catches were made early when low temperatures were likely suppressing pike movements. Movements of longnose suckers into both channels of Goose Creek were predominantly nocturnal. Nightly movements of suckers were especially evident into the east channel (Table 10). On May 7, about three times as many suckers were caught in the afternoon as were captured in the morning. Tallies kept on the numbers of burbot caught were not sufficient to draw any conclusions on their diel movements (Table 11).

Table 8. Daily numbers of Arctic grayling caught in hoop nets in the east and west channels of Goose Creek during the morning and afternoon.

Date	East Channel		West Channel	
	AM	PM	AM	PM
April 28	1	4		
29	3	-		
30	2	-		
May 1	-	-		
2	-	-		
3	-	-		
4	-	-		
5	-	-		
6	-	-		
7	-	-	-	1
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	1	-	1	-
12	-	-	-	-
13	-	-	-	-
14	-	-	-	-
Totals	7	4	1	1

Table 9. Daily numbers of northern pike caught in the hoop nets in the east and west channels of Goose Creek during the morning and afternoon.

Date	East Channel AM	East Channel PM	West Channel AM	West Channel PM
April 28	15	17		
29	4	10		
30	9	2+		
May 1	-	-		
2	-	-		
3	-	-		
4	-	-		
5	-	-		
6	-	-		
7	-	-	1	21
8	-	-	11	5
9	-	-	21	2
10	-	-	16	12
11	-	-	6	3
12	-	-	19	-
13	-	-	17	-
14	-	-	5	-
Totals	28	29	96	43

\+ These fish were released without being tagged.

Table 10. Daily numbers of longnose suckers caught in hoop nets in the east and west channels of Goose Creek during the morning and afternoon.

	East Channel		West Channel	
	AM	PM	AM	PM
April 28	1	3		
29	56	2		
30	51	-		
May 1	-	-		
2	-	-		
3	-	10		
4	38	-		
5	35	22		
6	-	-		
7	-	-	59	170
8	-	-	106	3
9	-	-	81	45
10	-	-	19	-
11	-	7	5	-
12	1	-	6	-
13	-	-	4	-
14	-	-	1	-
Totals	182	44	281	218

s in

Table 11. Daily numbers of burbot caught in hoop nets in the east and west channels of Goose Creek during the morning and afternoon.

Date	East Channel		West Channel	
	AM	PM	AM	PM
April 28	-	3		
29	3	-		
30	7	-		
May 1	-	-		
2	-	-		
3	-	3		
4	1	-		
5	5	1		
6	-	-		
7	-	-	7	27
8	-	-	-	-
9	-	-	-	-
10	-	-	-	13
11	-	1	-	-
12	-	-	14	-
13	-	-	17	-
14	-	-	2	-
Totals	16	8	40	40

Out of the 13 Arctic grayling that were tagged and released at Goose Creek, none was recovered. Although the gillnetting of grayling upstream of the culverts, and particularly in the west channel, was more successful than the downstream hoop netting (Table 12), none of these fish was tagged.

Twenty-six (13.1%) of the 198 northern pike tagged and released at Goose Creek were later recovered (Table 13). All of the recoveries except one, were made in Goose Creek. The exception was a pike caught in the Churchill River 13 km south or upstream of the Goose Creek confluence. Most of the recoveries (17) were made very shortly after release. Four of these recoveries were from the gill net set (Gill Net #3) in the east channel (Table 14). These fish were all caught and released below the culverts in the west channel between May 7 and 13, and recaptured within two days (i.e. between May 8 and 15). Mean water velocities in culvert 4 varied between a negative value (due to back flows from the Churchill River) and 1.22 m s^{-1} (4 fps) from May 7 to 15 (Fig. 11). Low flow velocities for the same time period ranged from -V to about 1.10 m s^{-1} (3.6 fps). Velocities (mean and low) in culvert 5 were considerably lower than in culvert 4 between May 7 and 15. Although it is highly likely that a large number of pike moved through culverts 4 and 5 during the backwater flows, it is believed that, at other times, pike swam upstream primarily through culvert 5. Gill Net #3 was directly opposite culvert 5 and would therefore readily intercept fish moving through the culvert. (The total catch in Gill Net #3 was 26 fish contrasted to only 17 in Gill Net #2 which was set opposite culvert 4). In culvert 5, the low velocities were generally well below 0.91 m s^{-1} (3.0 fps) (Fig. 12). Water velocities in culvert 5 may even have been lower than the 0.61 m s^{-1}

Table 12. Numbers of Arctic grayling gillnetted in the east and west channels of Goose Creek in May, 1977.

Date	East Channel	West Channel
May 7	-	-
8	-	-
9	-	-
10	-	3
11	-	3
12	-	1
13	-	-
14	-	6
15	1	4
16	-	12
Total	1	29

Table 13. Recaptures of tagged northern pike released from hoop nets set below the Goose Creek crossing in April and May, 1977.

Tag No.	Date Tagged	Recapture Date	Release Location	Recapture Location	Tagged F.L. (cm)
06272	77 04 27	77 04 29	Below Culvert #1*	Below Culvert #1	48.0
06329	77 04 28	77 04 29	" "	" "	51.5
06336	77 04 28	77 05 08	" "	" "	38.0
06413	77 04 30	78 06 03	" "	Goose Ck. below culverts	62.0
06934	77 05 07	77 05 08	Below Culvert #4	Gill Net #3	52.0
06978	77 05 08	77 05 10	" "	Below Culvert #4	33.0
08063	77 05 08	78 09 18	" "	In Goose Ck.	41.5
08077	77 05 08	77 05 09	" "	Below Culvert #4	42.0
08081	77 05 08	77 05 10	" "	" "	28.0
08138	77 05 09	78 06 28	" "	Goose Ck. below culverts	38.2
08139	77 05 09	77 05 10	" "	Below Culvert #4	38.5
08139	77 05 09	77 05 12	" "	" "	38.5
08142	77 05 09	77 05 11	" "	" "	33.5
08214	77 05 09	77 05 11	" "	Gill Net #3	43.5
08235	77 05 09	77 05 10	" "	Below Culvert #4	47.3
08257	77 05 10	78 05 27	" "	Churchill R 13 km S of Goose Ck	54.0
08277	77 05 10	78 06 27	" "	Goose Ck. below culverts	60.0
08281	77 05 10	77 06 24	" "	" " " "	60.0
08283	77 05 10	77 06 10	" "	Goose Ck. mouth	58.0
08288	77 05 10	77 05 11	" "	Gill Net #3	60.0
08302	77 05 10	77 06 11	" "	Goose Ck. above culverts	87.0
08327	77 05 11	79 07 07	" "	Goose Ck. above culverts (W. ch.)	40.0
08342	77 05 12	79 07 02	" "	In Goose Creek	33.0
08389	77 05 13	79 07 09	" "	Goose Ck. above culverts (W. ch.)	46.0
08402	77 05 13	77 07 02	" "	Near CN trestle	44.0
08428	77 05 13	77 05 14	" "	Below Culvert #4	36.0
08428	77 05 13	77 05 15	" "	Gill Net #3	36.0
08431	77 05 14	78 06 03	Below Culvert #4	Goose Ck. below culverts	39.0

*This specimen was initially caught by angling, not by the hoop net set downstream of Culvert #1.

Table 14. Numbers of northern pike gillnetted in the east and west channels of Goose Creek in May, 1977. Numbers of marked fish in parentheses.

Date	East Channel	West Channel
May 7	-	-
8	-	4(1)
9	-	2
10	-	10
11	-	8(2)
12	-	-
13	-	-
14	-	-
15	1	11(1)
16	-	11
Totals	1	46(4)

(2.0 fps) recorded. For example, immediately along the sides and bottom of the culvert where surface friction would reduce water velocities. The four tagged pike which moved through the crossing ranged in fork length from 36 to 60 cm ($\bar{x}$ = 47.9 cm). Two pike, between 30 and 40 cm in length, were actually observed moving upstream in culvert 5. The first (35-40 cm) was observed on the evening of May 8 and the second (30-35 cm) on May 10. The low water velocities recorded in culvert 5 on these dates were 0.73 and 0.61 m s^{-1} (2.4 and 2.0 fps), respectively. In addition to the 17 first-year recaptures, six pike were recovered by anglers in the second year (1978) and three in the third year (1979). The third-year recoveries were made above the Goose Creek crossing. They were all made in July so it is not known if they were able to negotiate the culverts during spring run-off conditions.

Only 3.6 per cent of the 725 longnose suckers that were tagged and released in Goose Creek were recaptured. Most of the recoveries (16) were made in May, 1977; the remainder were caught in 1978 (Table 15). It is interesting to observe that suckers tagged and released in the east channel (below culvert 1) were primarily recovered in the west channel. The reverse movement was observed only once. The majority of recoveries were made downstream of the crossing. Only one tagged sucker was recaptured upstream of the crossing. This individual was released below culvert 4 and recaptured on May 10 in Gill Net #3. It had a fork length of 45.0 cm. As was speculated in the case of pike, this and other suckers probably used culvert 5 in preference to the other culverts to move upstream of the crossing. Virtually the same number of longnose suckers as northern pike were caught in the west channel of Goose Creek (Table 16). However, greater

Table 15. Recaptures of tagged longnose suckers released from hoop nets set below the Goose Creek crossing in April and May, 1977.

Tag No.	Date Tagged	Recapture Date	Release Location	Recapture Location	Tagged F.L. (cm)
06315	77 04 29	77 05 09	Below Culvert #1	Below Culvert #4	47.0
06406	77 04 30	77 05 09	" "	" "	43.5
06448	77 04 30	77 05 12	" "	" "	45.5
06448	77 04 30	77 05 17	" "	" "	45.5
06456	77 05 03	78 05 06	" "	Goose Ck below culverts	42.0
06517	77 05 04	78 05 27	" "	" " " "	41.5
06571	77 05 05	78 05 19	" "	" " " "	43.0
06596	77 05 05	78 06 07	" "	" " " "	44.0
06602	77 05 05	77 05 14	" "	Below Culvert #4	44.0
06603	77 05 05	77 05 09	" "	" "	46.0
06620	77 05 07	77 05 11	Below Culvert #4	" "	45.5
06638	77 05 07	77 05 09	" "	" "	46.8
06726	77 05 07	78 06 07	" "	Goose Ck below culverts	45.0
06862	77 05 07	77 05 12	" "	Below Culvert #4	43.0
06898	77 05 07	77 05 11	" "	" "	45.0
06924	77 05 07	78 06 01	" "	In Goose Ck.	40.0
06978	77 05 08	77 05 10	" "	Below Culvert #4	33.0
08018	77 05 08	77 05 08	" "	" "	42.8
08036	77 05 08	78 08 --	" "	Found Dead	46.6
08053	77 05 08	77 05 09	" "	Below Culvert #4	40.6
08112	77 05 09	78 06 04	" "	In Goose Ck.	42.3
08147	77 05 09	78 05 20	" "	Goose Ck below culverts	41.5
08221	77 05 09	77 05 10	" "	Gill Net #3	45.0
08225	77 05 09	77 05 11	" "	Below Culvert 1	49.8
08229	77 05 09	78 06 07	" "	Goose Ck below culverts	45.0
08343	77 05 12	77 05 13	" "	Below Culvert #4	47.0
08369	77 05 12	77 05 13	Below Culvert #1	" "	44.0

Table 16. Numbers of longnose suckers gillnetted in the east and west channels of Goose Creek in May, 1977. The number in parenthesis is a marked fish.

Date	East Channel	West Channel
May 7	-	6
8	-	8
9	-	2
10	-	10(1)
11	-	2
12	6	-
13	1	-
14	3	4
15	1	-
16	5	15
Totals	16	47

numbers of suckers than pike were gillnetted above the culverts in the east channel. This might suggest that some longnose suckers were able to overcome water velocities in the east channel culverts. Water velocities in culverts 1, 2 and 3 were above 0.91 m s^{-1} (3 fps) during the period May 12 to 16 (Figs. 8-10), except on May 15 when the Churchill River backed into Goose Creek. Consideration should also be given to the possibility that suckers from the west channel upstream of the crossing moved into the east channel. The 10 second-year recoveries were made almost exclusively in May and early June, which suggests that the longnose suckers were returning to Goose Creek to spawn.

Only six (5.8%) of the 104 burbot which were tagged were recaptured. All recoveries were made below the west channel culverts even though some had been released in the east channel (Table 17). No tagged burbot was recovered upstream of the crossing. All burbot caught in upstream gillnetting were caught in the west channel (Table 18).

Only four whitefish were caught in the hoop net set in the west channel. No whitefish was caught below the culverts in the east channel. The catch of whitefish in gillnets set in Goose Creek upstream of the crossing (58 fish) was substantially better than the downstream catch. As was the case for the other species, most of the whitefish were also caught in the west channel (Table 19).

Results of gillnetting conducted on Warkworth Lake were too limited to determine fish passage through the culverts. The following catch was made in the 24 hr set of 38.1 m of 7.6 cm (stretched measure) mesh:

17 longnose suckers

7 burbot

Table 17. Recaptures of tagged burbot released from hoop nets set below the Goose Creek crossing in April and May, 1977.

Tag No.	Date Tagged	Recapture Date	Release Location	Recapture Location	Tagged T.L. (cm)
06373	77 04 29	77 05 17	Below Culvert #1	Below Culvert #4	61.5
06429	77 04 30	77 05 17	" "	" "	51.0
06427	77 04 30	77 05 05	" "	Below Culvert #1	60.0
06451	77 04 30	77 05 07	" "	Below Culvert #4	56.0
06833	77 05 07	77 05 10	Below Culvert #4	" "	32.0
06852	77 05 07	77 05 10	" "	" "	41.0

Table 18. Numbers of burbot gillnetted in the east and west channels of Goose Creek in May, 1977.

Date	East Channel	West Channel
May 7	-	-
8	-	-
9	-	3
10	-	3
11	-	2
12	-	-
13	-	-
14	-	-
15	-	-
16	-	1
Total	0	9

Table 19. Numbers of whitefishes* (both lake and round whitefish) gillnetted from the east and west channels of Goose Creek in May, 1977.

Date	East Channel	West Channel
May 7	-	2
8	-	7
9	-	1
10	-	6
11	-	5
12	3	5
13	-	3
14	1	1
15	2	4
16	-	18
Totals	6	52

* From May 12, the numbers of lake whitefish and round whitefish caught are 17 and 20, respectively.

4 Arctic grayling

1 northern pike.

One of the longnose suckers (a ripe male) bore a tag; details on its tagging and release were not recorded. Seven of the suckers were spent fish, five were ripe females and one female was still hard. All of the Arctic grayling and the northern pike were spent.

During the last week of monitoring, the sexual condition of northern pike and longnose suckers was examined. Well over half (62%) of the pike were spent or in spawning condition (Table 20). About 50 per cent of the longnose suckers were spawning or had already spawned (Table 21). A small proportion (9-12%) of the pike and sucker runs consisted of immature fish. Additional details on the data presented in Tables 20 and 21 are given in Appendices C and D. All Arctic grayling caught upstream and downstream of the culverts were spent.

The hoop net catches in the east and west channels of Goose Creek and the immediate recoveries made in the hoop nets allowed estimation of population size of northern pike and longnose suckers. The fishing and tagging done at Goose Creek below the culverts generally satisfied the six conditions of a mark-recapture experiment (Ricker, 1975). Only two of the conditions may not have been fully met. The tagged fish, having been caught once already, may not have been as vulnerable as unmarked fish. Also, the tagged fish may not have mixed randomly with the unmarked fish. There is a possibility that the marked fish, if not successful in stemming the currents in the culverts, moved elsewhere (back to the Churchill River) and were replaced by new arrivals in the spawning runs of pike and suckers. The above causes may account for the low number of recaptures in the hoop nets. However, since the pike and suckers were in spawning condition, the urge to remain in Goose

Table 20. Gonad condition of northern pike sampled at Goose Creek from May 13-19, 1977.

Date	Gonad Condition				
	1	2	3	4	5
May 13	-	-	-	1	-
14	-	-	-	1	-
15	3	1	2	-	6
16	2	-	-	-	4
17	1	1	2	4	2
18	-	3	1	2	5
19	-	-	-	-	1
Totals	6 (14.3%)	5 (11.9%)	5 (11.9%)	8 (19.0%)	18 (42.9%)

1 = Undetermined gonad condition

2 = Immature

3 = Gravid female

4 = Ripe male or female, milt or eggs easily extruded

5 = Spent male or female

Male: Female Sex Ratio 1.47:1.00

Table 21. Gonad condition of longnose suckers sampled at Goose Creek from May 14-19, 1977.

Date	Gonad Condition*				
	1	2	3	4	5
May 14	-	-	-	1	-
15	-	-	1	-	-
16	6	-	-	-	2
17	1	3	-	1	3
18	-	-	-	-	-
19	4	-	1	4	6
Total	11 (33.3%)	3 (9.1%)	2 (6.1%)	6 (18.2%)	11 (33.3%)

* See Table 20

Male:Female Sex Ratio 0.76:1.00

Creek may have been strong enough to overcome "trap-shyness" or any proclivity to return to the Churchill River. This speculation is given some credence with the observation that two fish (one pike and one sucker) were recaptured twice after tagging. The pike had remained in the area at least four days and the sucker 18 days. If there was any movement during the study period it was from the east to the west channel where upstream egress appeared to be easier. Assuming these latter conditions pertain, then the low number of recoveries in the downstream hoop net may have been due to dilution; i.e. the mixing of the tagged fish coming into Goose Creek and milling below the culverts.

Schumacher-Eschmeyer estimates (Ricker, 1975) indicated a much larger population of longnose sucker than northern pike (Appendices E-H). The population of longnose suckers appeared to be about five to ten times larger than the pike population (Table 22). This did not agree with the ratio of pike and sucker catches in the hoop nets. Approximately two suckers were caught for each pike captured. Although it is normal for suckers to be more numerous than pike in an area, the Goose Creek sucker population estimate is doubtful (Table 22). It is speculated that the sucker population in Goose Creek was more in the order of 5000 fish. This population size is more in agreement with the 2:1 ratio of sucker/pike catches.

During the 1977 study, brief observations were made on food of some of the pike, Arctic grayling, lake whitefish, round whitefish and burbot in Goose Creek (Appendix J). Fish eggs were observed in the diet of both pike and burbot. A relatively higher proportion of burbot than pike fed on fish eggs. It appeared that at least 25 per cent of the burbot may have been feeding on fish eggs.

Table 22. Schumacher-Eschmeyer population estimates of spawning-run northern pike and longnose suckers in Goose Creek, April-May, 1977.

Species	Area	Population estimate	95% confidence interval
N. Pike	Both channels	1763	1157 - 3701
	West channel	1154	621 - 8173
Longnose sucker	Both channels	10637	5457 - 209,952
	West channel	6425	*

* Negative upper limit

On May 14, a diver checked the area immediately below the culverts for spawned eggs. A surface check was also made at the same time. No evidence was found that pike or suckers had spawned in Goose Creek below the culverts. During the dive, one adult brook was observed.

DISCUSSION

The adequacy of the Goose Creek crossing design is difficult to fully assess because of the lack of a hydrometric record for Goose Creek. Although this report did not consider the estimated discharge regime of Goose Creek in detail, there is some question as to the accuracy of the estimated Q_{50} (92 $m^3 s^{-1}$) for Goose Creek. Other studies on northern streams have shown higher discharges for streams draining much smaller areas. Dryden and Jessop (1973) estimated a Q_{50} of 113 $m^3 s^{-1}$ for a Mackenzie Valley stream with a drainage area of 246 km^2 or less than half the Goose Creek drainage area. In another case, a stream with a 400 km^2 basin in a permafrost area was estimated to have a theoretical peak flow of 105 $m^3 s^{-1}$; the return period was not specified but it is probably the Q_{50} flow (Anonymous 1973). This basin, which is located in the lower MacKenzie River Delta, in many respects resembles the Goose Creek basin. Both areas are underlain with permafrost and possess similar relief, climate and vegetation. Discharge envelope curves developed for streams in the Northwest Territories provide an estimated Q_{50} of 170 $m^3 s^{-1}$ for a stream with a drainage area like that of the Goose Creek basin (Katopodis, 1976b). The discharges of Goose Creek may therefore be underestimated by as much as almost 100 per cent.

If the estimated discharge regime for the Goose Creek basin is accepted as correct, then the crossing as designed should prove adequate, at least for the purpose of conveying stream flows. Based upon the 1977 flow data, it is evident that the five culverts in the Goose Creek crossing are capable of accommodating discharges equivalent to the estimated Q_{50}. A discharge of 92 $m^3 s^{-1}$ will completely fill all five culverts; there will be no freeboard in the culverts to allow

for the passage of large debris or ice. Discharges greater than 92 $m^3 s^{-1}$ will result in excessive ponding, inundation of the road grade, erosion and probably wash-outs. Most of the events have already occurred.

Observations were made on Goose Creek during the spring run-off in 1979. On May 28-30, water velocities were measured at all five culvert outlets during peak flow conditions; water level apparently crested on May 27. Using these data and based on the relationship found between water velocities and discharges in 1977 (Figs. 14 and 16), spring discharges in Goose Creek in 1979 could have been as high as 85 $m^3 s^{-1}$. Under these conditions, all culverts were flowing at nearly full capacity, water velocities through the culverts were high and some ponding was occurring. Water velocities in the east channel culverts averaged 2.76 m s^{-1} (9.05 fps) and 2.09 m s^{-1} (6.87 fps) in the west channel culverts. Ice jams within the culverts reduced their capacity and errosive processes had begun. The road grade had to be breached to relieve pressure on the crossing and prevent it from washing out (D. Cook, personal communication). It appears the Goose Creek crossing may be adequate to pass the design flow (92 $m^3 s^{-1}$), but will be in jeopardy should any of the culverts become clogged.

Observations on culvert water velocities at the Goose Creek crossing and their comparison with the findings of other studies suggest the Goose Creek crossing constituted a virtual barrier to upstream passage of mature fish during the 1977 spring runoff period. Except for one culvert, average water velocities across the downstream end of the Goose Creek culverts varied closely about 1.22 m s^{-1} (4 fps). Water velocities at the upstream ends were at least 0.30 m s^{-1} higher. Culverts

are generally considered impassable when the average velocity across any section in the culverts exceed 1.52 m s^{-1} (5 fps) (Sellars, 1973 and Engel, 1974). It has been recommended that maximum water velocities in culverts not exceed 1.22 m s^{-1} for trout (Evans and Johnston, 1972). Metsker (1970) suggested water velocities not exceed 1.83 m s^{-1} for 38 cm trout. Since those fishes inhabiting Goose Creek (Arctic grayling, longnose suckers, northern pike, etc.) have much poorer swimming performances than trout (Bell, 1973), it is evident water velocities experienced in the Goose Creek culverts would render them impassable. More recent studies indicate water velocity requirements in culverts which will permit fish passage are much more stringent than previously thought. Jones et al. (1974) measured the swimming performances of a number of freshwater fish species in the Northwest Territories with a view to determining their ability to pass through highway culverts. They concluded that in order to allow the successful passage of mature migratory fish, water velocities should be generally less than 0.30 to 0.40 m s^{-1} (1.0 to 1.3 fps). Dryden and Stein (1975) state that the average cross-sectional velocity through any culvert section shall not exceed 0.91 m s^{-1} (3 fps) unless there is a section in the culvert wherein velocities are low enough to pass fish upstream.

Results from the tagging and recapture operations indicated that very few fish were able to pass upstream of the crossing. None of the 13 Arctic grayling released below the crossing was recovered. However, more grayling were caught upstream of the crossing which suggests they may have been able to negotiate the water velocities through the culverts. There is also the possibility that grayling from Warkworth Lake moved downstream. Out of the 25 northern pike recovered, only 4

(16%) were recaptured upstream of the crossing shortly after release (i.e. within two days). Average size of these pike was 48 cm and they ranged from 36 to 60 cm. Although these pike moved upstream through the west channel culverts where water velocities were appreciably lower, it is not known whether they moved through the crossing at times when minimum water velocities ranged between 0.60 and 1.10 m s^{-1} (2.0 to 3.6 fps) or during the brief period when Goose Creek flows reversed because of backwater from the Churchill River. If the pike did move upstream during normal conditions (i.e. not during backwater flows), it is believed they moved through culvert 5 in which lowest velocities were observed. Although routine visual checks were not made for fish swimming into the culverts, actual movement of pike into culverts was only observed in culvert 5. The two pike, which were 30 to 40 cm long, were observed when the lowest water velocities through culvert 5 ranged between 0.60 and 0.70 m s^{-1} (2.0 to 2.3 fps). As will be further discussed below, these velocities were likely too strong and the pike observed within the culvert were unable to swim the entire length of the culvert. The tagged pike recaptured above the Goose Creek crossing therefore may have moved through the culverts during the backwater flows from the Churchill River. Since only one of the 725 longnose suckers tagged downstream of the crossing, it is evident the culverts blocked the upstream passage of most suckers. This is rather unusual since longnose suckers show a better swimming performance than pike (Jones et al., 1974). No burbot was recovered upstream of the crossing. This is not too unusual since they were not in spawning condition and would not have the same drive to move upstream as would fish in a spawning run (MacPhee and Watts, 1975).

As in the case of Arctic grayling, not enough whitefish were marked to determine if any moved through the culvert. The presence of both burbot and whitefish in Goose Creek was because both species were in search of food. The movement of burbot into Goose Creek may have been to feed upon the spawned eggs of pike and suckers. This author observed a inshore movement of burbot in Lake Winnipeg just as lake whitefish began spawning on reefs.

In order to determine whether water velocities through the Goose Creek culverts exceeded the swimming capabilities of the fishes found in Goose Creek in April-May, 1977, information provided by Jones et al. (1974) was used. Jones et al. (1974) determined the prolonged or sustained swimming performances, as related to size, of 10 species of Mackenzie River fish. Prolonged swimming speed may be generally defined as the speed a fish can maintain for several minutes or more. Burst and cruising speeds, on the other hand, are speeds which fish can maintain for a few seconds and an hour or more, respectively (Watts, 1974). The swimming performance of fish will vary depending on body length (Bainbridge, 1960 and Fry and Cox, 1970) and species as well as a variety of other factors; eg. sexual condition, sex, temperature, dissolved oxygen, disease, etc. The experiments conducted by Jones et al. (1974) considered many of these variables and included fish species found in Goose Creek. They determined the relationship between the fork length of fish and their ability to swim 100 m in 10 min against water velocities as high as 0.80 m s^{-1} (2.62 fps). These relationships were determined for burbot, northern pike, lake whitefish, longnose sucker, and Arctic grayling as well as other species. The above relationships were determined for pike, lake whitefish, grayling and longnose sucker considering a distance of 27.4 m, the length

of the culverts employed in the Goose Creek crossing (Fig. 23). The curve for burbot is not shown since Jones et al. (1974) did not find a relationship which was statistically significant at the 5 per cent level. Considering the average and range in sizes of pike and suckers (Table 7, Figs. 20 and 21), it is estimated from Fig. 23 that water velocities through the Goose Creek crossing should be approximately 0.35 m s^{-1} (1.2 fps) for average-sized pike and 0.77 m s^{-1} (2.5 fps) for suckers of average size to swim through the 27.4 m culverts. If smaller pike (i.e. the minimum size observed in the spawning or less than 35 cm) are to be able to move through the crossing, water velocities should be in the order of 0.25 m s^{-1} (0.8 fps). To allow the smaller suckers to move through the Goose Creek culverts, water velocities should be about 0.55 m s^{-1} (1.8 fps). For the average size of Arctic grayling caught in Goose Creek spawning run (38 cm), the velocity through the culverts should be approximately 0.60 m s^{-1} (2.0 fps). Water velocities greater than 60 cm/s, however, would not stop the upstream movement of all grayling. MacPheee and Watts (1975) found that water velocities in a 30.5 m culvert of 0.91 m s^{-1} would allow the passage of 75 per cent of all grayling approximately 25 cm in length. On the other hand a water velocity of 1.5 m s^{-1} (3.3 fps) rendered a 30.5 m culvert impassable to all grayling less than 30 cm long. Since grayling may mature at a size less than 30 cm (Renewable Resources Ltd., 1972) and since the culvert design should allow for more passage than 75 per cent, water velocities through the Goose Creek culverts should be at most 0.60 m s^{-1} and less if possible. Data on the size of lake and round whitefish caught in Goose Creek were not compiled so it cannot be estimated what water

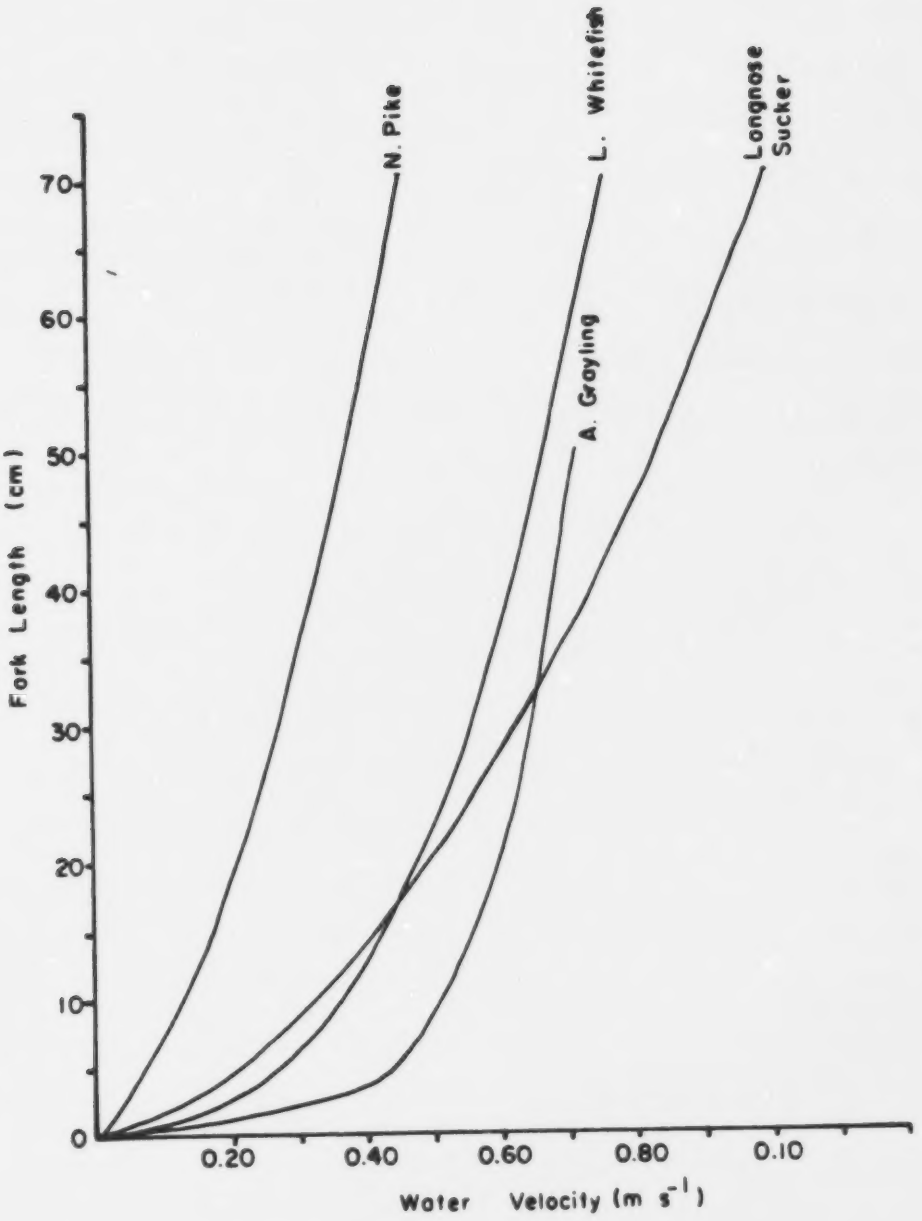

Figure 23. The relationship between fork length of northern pike, lake whitefish, Arctic grayling and longnose suckers and their ability to move 27.4 m in 10 min against various water velocities (after Jones et al. 1974).

velocities through the culverts should have been to permit their passage. However, assuming that the average size of lake whitefish was 35 cm, then water velocities should not be greater than 0.55 m s^{-1} (1.8 fps).

It is evident that water velocities through the Goose Creek culverts were sufficiently high enough during the 1977 spring runoff period to form an almost complete barrier to all fish species of most size-ranges observed in Goose Creek. A possible exception to this conclusion is the Arctic grayling. Since this species may swim under the ice or in flowing channels in the ice towards its spawning ground (Watts, 1974), it could have moved through the Goose Creek crossing before flows became impassable. For the other spring-spawning fishes, northern pike and longnose suckers, velocities through the culverts should have been 0.55 m s^{-1} or less. The velocities only dropped below this level in all five culverts once on May 15. At this time most of the fish running into Goose Creek were in the west channel. Interviews with residents of Churchill indicated that the spring run of fish into Goose Creek was always heaviest in the west channel. This is probably due to the lower discharges and water velocities in the west channel as well as other factors. On May 14 and 15, flows in west channel actually reversed. Since the orientation of fish in Goose Creek at the time was upstream, they would tend to move back into the Churchill River with the reversal of flows. This would explain why larger numbers of fish, both tagged and untagged, were not captured upstream of the crossing after the reversed flows occurred.

The impacts resulting from the blockage of fish passage at the Goose Creek crossing in 1977 will not be entirely known until some years into the future. Monitoring of fish movements in Goose Creek

may not have begun early enough to adequately discern whether grayling had sufficient time to move above the crossing and reach their spawning areas. All grayling caught were spent. In the case of the northern pike and longnose suckers, all specimens examined during the last week of monitoring were in a spawning condition or spent (Tables 20 and 21). This indicates the pike and suckers would not have been able to reach upstream spawning areas in time even if water velocities through the culverts had declined sufficiently during the latter part of May. The fish therefore either spawned in sub-optimal or over-crowded areas or resorbed their eggs. Loss of reproductive potential for pike will have serious consequences in the pike population. The population is quite small and may not be able to tolerate the combined effects of angling intensity and loss of spawning habitat. Loss of spawning habitat will also reduce the longnose sucker population. This would benefit the grayling population in Goose Creek by providing them with more space and food. However the reduction in sucker population could shift or increase predation on grayling and negate any advantage the reduced sucker population may have provided. The outcome of blocking fish movements, during the spring and other periods of the year cannot be predicted with certainty. It can be predicted with some assurance, however, that the Goose Creek crossing will exert an negative influence on the fish populations of the area.

SUMMARY AND RECOMMENDATIONS

Goose Creek, which flows into the Churchill River 11 km west of the town of Churchill, drains an area of 620 km^2. The creek is crossed near its lower end by five arch rib, multiplate culverts which are 27.4 m long with an opening of 2.7 x 3.9 m. The crossing is at a braided section of the stream with two major channels; there are three culverts in the east channel and two in the west.

Flows at the Goose Creek crossing were monitored from April 29 to May 20, 1977. The mean daily discharge recorded in the east channel was 16.4 $m^3 s^{-1}$. The average discharge in the west channel was 8.4 $m^3 s^{-1}$. Water velocities through the east channel culverts were greater than 0.91 m s^{-1} on 20 days. Water velocities exceeding 0.91 m s^{-1} were observed in the two east channel culverts on 10 days. Average water velocities throughout the 22 day monitoring period exceeded 0.91 m s^{-1} in all five culverts. Water velocities were routinely measured at the downstream end of the culverts. Water velocities at the upstream end were about 0.90 m s^{-1} greater.

Because there were only two culverts in the west channel, estimated water velocities through the west channel culverts tended to be about 0.90 m s^{-1} higher than through the east channel culverts at given discharges (Table 3). It was estimated that stream discharges in excess of 85 $m^3 s^{-1}$ the 50-year flood, would fill the five culverts to capacity and inundate the crossing.

Spring breakup at Goose Creek, as judged from meteorological records, began early in 1977. A total of 1044 fish were captured in hoop nets set immediately below the Goose Creek crossing. The major

species in the spawning run was longnose suckers. They constituted 69.4 per cent of the recorded catch; all burbot caught were not recorded. Northern pike, which were also on their spawning run, made up 19.0 per cent of the catch. Burbot, lake whitefish, and round whitefish were caught moving into Goose Creek. Only 13 Arctic grayling were caught downstream of the crossing; more (30) were caught upstream.

Most (69%) of the fish caught in Goose Creek were caught below the west channel culverts. The mean lengths of pike, suckers and burbot were greater in the east channel than the west channel. However, there were usually more larger pike and suckers in the west channel. The differences in sizes of fish in the east and west channels were not statistically significant.

There were diel difference in fish movements. It appeared that both pike and suckers moved into Goose Creek during the evening or hours of darkness.

None of the 13 tagged Arctic grayling was recaptured. Twenty-six of the 198 tagged pike were recovered; all recoveries except one were in Goose Creek. Seventeen of the pike recoveries were made during the monitoring period. Only four of these recoveries were upstream of the crossing. These fish apparently moved through the west channel culverts. Water velocities through the culverts at the time passage was made varied from reverse flows to 1.10 m s^{-1}. The four pike ranged in length from 36 to 60 cm. Six pike were recovered in 1978 and two in 1979. Twenty-six of the 725 longnose suckers were recaptured; 16 during May, 1977. Only one recapture was made upstream of the crossing. Ten recoveries were made in 1978; almost all were caught in May and early June. Six burbot out of 104

were recovered; all were downstream of the crossing.

Observations of the sexual conditions of grayling, pike and suckers during the period May 7-14 indicated that all grayling were spent, and 50 per cent or more of the pike and suckers were in the final stage of spawning condition or spent.

Population estimates based on tag recoveries indicated that the population of adult or spawning pike in Goose Creek was about 1200 to 1800 fish. It was estimated that the adult population of longnose suckers was approximately 5000 fish.

It was concluded that the water velocities experienced in the Goose Creek culverts in 1977 presented a total or near-total barrier to the upstream spring migration of fish. Since the volume of runoff in Goose Creek in 1977 cannot be considered above average, it is evident the velocity barrier will be present in most succeeding years and create an unacceptably high degree of blockage.

It is recommended that corrective action be taken to prevent the blockage of upstream fish movement at the Goose Creek crossing. Although a more detailed engineering assessment and cost analysis of alternatives is required, the problem may be overcome by either installing more culverts, larger culverts or by replacing the culverts with a bridge. Consideration should be given to placing an additional culvert, of the size presently used, in the east channel. This would increase the capacity of the portion of the crossing to accommodate peak spring flows, reduce water velocities in the culverts to some degree, and perhaps allow some fish movements. Definite action should be taken to correct the crossing in the west channel, since it contains the heaviest runs of fish. Since it is doubtful the channel width could easily accommodate placement of an

additional culvert, consideration should be given to replacement of the culvert with a bridge or an open-bottom arch culvert.

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APPENDICES

Appendix A-1a: Daily water levels upstream (U/S) and downstream (D/S) of the road crossing and discharges in the east channel of Goose Creek and the mean and lowest water velocities in culverts 1 to 3.

Date	Water Levels (ft)		Water Velocity (fps)						Discharge (cfs)
			Culvert 1		Culvert 2		Culvert 3		
	U/S	D/S	Mean	Low	Mean	Low	Mean	Low	
April 29	18.08	16.98	5.13	3.90	5.71	4.73	5.42	4.78	724
30	17.96	16.83	4.80	3.54	5.56	4.96	5.03	4.29	525
1	17.27	16.81	2.32	2.08	2.95	2.24	3.03	2.68	404
2	17.68	16.81	4.31	3.65	4.80	3.85	4.65	4.30	689
3	17.76	16.82	4.77	3.76	4.93	4.15	4.66	3.79	720
4	17.82	17.03	3.89	2.93	4.09	2.66	4.50	4.06	615
5	17.76	16.95	4.40	3.88	4.76	4.30	4.85	4.60	705
6	17.78	16.92	3.38	2.98	4.38	3.37	4.35	3.57	613
7	17.64	16.70	4.28	3.43	4.74	4.06	4.36	3.57	667
8	17.52	16.63	4.19	3.43	4.63	4.15	4.24	3.56	627
9	17.49	16.59	4.02	2.85	4.52	3.72	4.27	3.88	609
10	17.43	16.66	3.82	3.05	4.21	3.15	3.89	3.12	560
11	17.41	16.51	4.13	3.08	4.20	3.18	4.07	3.57	579
12	17.18	16.37	4.05	3.57	4.45	3.88	4.19	3.35	566
13	17.15	16.18	4.30	3.88	4.66	4.20	4.39	3.19	573
14	16.96	16.11	3.72	3.57	4.36	3.97	4.59	3.69	522
15	17.34	17.14	2.04	1.44	2.21	1.64	2.31	2.13	330
16	17.90	17.12	3.79	2.79	4.33	3.40	4.22	3.27	644
17	17.62	16.82	4.29	3.37	4.69	4.10	4.52	4.15	650
18	16.93	15.95	4.06	3.25	4.43	4.06	4.19	3.27	533
19	16.48	15.70	3.67	3.27	3.97	3.37	3.75	2.66	445
20	16.28	15.46	3.49	2.78	3.96	3.15	3.75	3.15	400
$\bar{x}$	-	-	3.96	3.21	4.40	3.67	4.25	3.60	581

Appendix A-1b: Daily water levels upstream (U/S) and downstream (D/S) of the road crossing, and discharges in the west channel of Goose Creek and the mean and lowest daily water velocities in culverts 4 and 5.

Date		Water Levels (ft)		Water Velocity (fps) Culvert 4		Culvert 5		Discharge (cfs)
		U/S	D/S	Mean	Low	Mean	Low	
April	28	18.37	17.37	-	-	-	-	-
	29	-	-	4.89	4.45	4.12	3.84	402
	30	-	-	4.48	4.13	4.05	3.79	370
May	1	17.27	16.81	3.41	2.60	2.26	2.13	230
	2	17.97	17.14	[illegible]	3.80	3.91	3.37	399
	3	17.97	17.12	4.80	3.72	3.58	3.19	365
	4	17.96	17.37	3.82	3.65	3.22	2.79	325
	5	17.94	17.39	3.73	3.50	3.15	2.98	322
	6	17.94	17.45	2.90	2.31	2.92	2.57	263
	7	17.94	17.45	3.54	3.28	2.89	2.69	291
	8	17.73	17.19	3.46	3.19	2.89	2.43	282
	9	17.68	17.17	2.89	2.69	2.60	2.10	239
	10	17.67	17.32	3.01	2.85	2.40	2.02	235
	11	17.63	17.05	3.58	3.27	2.88	2.43	275
	12	17.57	16.91	3.74	3.57	3.00	2.40	282
	13	17.46	16.70	3.96	2.85	3.23	3.65	288
	14	17.26	16.64	-	-	-	-	-
	15	17.64	17.66			NO FLOW		
	16	18.06	17.51	3.16	2.74	2.70	2.24	288
	17	17.78	17.17	3.65	3.12	2.97	2.66	283
	18	17.27	16.18	4.81	4.20	3.49	2.92	296
	19	16.90	15.82	4.57	3.65	3.33	2.74	274
	20	16.69	15.47	4.46	4.30	3.40	2.60	249
	$\bar{x}$	-	-	3.89	3.39	3.14	2.77	297

Appendix A-2a: Daily water velocities (fps) recorded near the surface (S) and near the bottom (D) at three points across the downstream end of culvert 1.

	A		B		C	
	S	D	S	D	S	D
April 29	5.42	3.90	5.44	5.21	5.42	5.42
30	4.90	3.54	4.85	5.19	5.72	4.59
May 1	2.18	2.08	2.38	2.28	2.33	2.66
2	3.66	3.65	4.80	4.48	5.51	3.79
3	4.25	3.76	5.67	4.65	6.08	4.25
4	2.93	3.08	3.80	4.20	4.75	4.60
5	3.88	3.97	4.36	4.51	4.75	4.96
6	3.14	2.98	3.53	3.57	4.10	2.98
7	4.25	3.43	4.58	4.15	5.13	4.15
8	4.25	3.50	5.19	3.50	5.31	3.43
9	3.97	3.19	5.13	2.85	5.41	3.57
10	4.06	3.76	4.06	3.05	4.46	3.57
11	4.25	4.06	4.60	3.08	4.75	4.06
12	3.57	3.86	4.85	3.19	5.19	3.65
13	3.88	3.97	5.19	3.44	5.31	4.01
14	-	-	-	-	-	-
15	2.38	1.91	2.38	1.44	2.32	1.81
16	4.06	3.86	4.20	2.79	4.34	3.50
17	4.56	4.60	4.46	3.37	5.05	3.72
18	4.06	4.36	4.10	3.25	4.65	3.97
19	3.44	3.72	3.97	3.27	4.15	3.50
$\bar{x}$	3.85	3.56	4.38	3.57	4.74	3.81

Appendix A-2b: Daily water velocities (fps) recorded near the surface (S) and near the bottom (D) at three points across the downstream end of culvert 2.

	A		B		C	
	S	D	S	D	S	D
April 29	5.95	4.73	5.86	5.84	6.08	5.79
30	5.67	4.96	5.77	5.52	5.97	5.58
May 1	3.05	2.24	3.19	3.27	3.35	2.60
2	4.90	3.85	5.19	4.56	5.58	4.75
3	5.13	4.15	5.44	4.46	5.61	4.80
4	4.46	3.88	4.75	2.66	5.01	3.80
5	4.40	4.30	4.85	5.13	5.01	4.85
6	4.75	3.37	4.96	4.15	4.96	4.10
7	5.25	4.06	5.25	4.36	5.13	4.41
8	3.88	4.15	4.70	4.56	5.07	4.46
9	4.70	3.72	4.75	4.54	5.07	4.36
10	4.65	3.15	4.36	4.20	4.80	4.10
11	4.80	3.18	4.63	3.27	4.96	4.36
12	4.46	3.88	4.46	4.63	4.85	4.41
13	4.36	4.20	5.07	4.74	4.73	4.85
14	-	-	-	-	-	-
15	2.54	1.64	2.66	1.99	2.60	2.13
16	4.25	3.40	4.65	4.41	4.85	4.44
17	5.19	4.10	4.38	4.80	5.44	4.38
18	4.06	4.20	4.73	4.56	4.70	4.36
19	3.61	3.37	4.75	3.88	4.23	3.97
$\bar{x}$	4.50	3.73	4.72	4.28	4.90	4.32

Appendix A-2c: Daily water velocities (fps) recorded near the surface (S) and near the bottom (D) at three points across the downstream end of culvert 3.

	A		B		C	
	S	D	S	D	S	D
April 29	5.42	4.78	5.17	3.90	5.57	5.65
30	4.59	4.29	5.19	5.44	5.44	5.19
May 1	2.79	3.12	3.27	2.98	3.35	2.68
2	4.36	4.56	4.30	4.80	4.85	5.05
3	4.75	3.79	4.96	4.75	4.96	4.75
4	4.96	4.06	4.46	4.36	4.80	4.36
5	4.65	4.75	4.60	5.07	4.75	5.31
6	4.15	3.57	4.25	4.46	4.75	4.96
7	4.25	3.57	4.28	4.46	4.90	4.73
8	3.88	3.56	3.97	4.44	5.07	4.51
9	3.88	3.88	3.97	4.06	5.19	4.63
10	4.06	3.12	3.84	3.50	4.75	4.10
11	4.10	3.57	4.15	3.78	4.96	3.88
12	3.88	3.35	4.38	4.51	4.80	4.25
13	3.80	3.19	4.96	4.60	5.31	4.51
14	-	-	-	-	-	-
15	2.24	2.13	2.38	2.24	2.54	2.33
16	4.46	3.27	4.36	4.06	4.75	4.46
17	4.56	4.65	4.65	4.36	4.75	4.15
18	3.65	3.27	4.36	3.65	4.96	4.36
19	2.98	2.66	3.97	3.92	4.56	4.44
$\bar{x}$	4.07	3.66	4.27	4.17	4.75	4.42

Appendix A-2d: Daily water velocities (fps) recorded near the surface (S) and near the bottom (D) at three points across the downstream end of culvert 4.

		A		B		C	
		S	D	S	D	S	D
April	29	4.45	4.83	4.83	5.29	5.05	4.92
	30	4.13	4.29	4.56	4.56	4.67	4.65
May	1	3.19	3.57	3.50	2.60	3.88	3.72
	2	3.80	4.65	5.07	5.07	5.07	5.07
	3	3.72	4.82	4.96	5.19	5.31	4.75
	4	3.88	3.65	3.72	3.91	3.92	3.76
	5	3.72	3.80	3.50	3.88	3.57	3.91
	6	3.22	2.31	3.28	2.66	3.57	2.38
	7	3.50	3.88	3.37	3.40	3.92	3.28
	8	3.25	3.19	3.49	3.80	3.50	3.57
	9	2.92	2.69	2.74	3.06	2.98	2.98
	10	2.92	3.05	2.85	3.19	3.12	2.97
	11	3.68	3.27	3.65	3.78	3.65	3.50
	12	3.65	3.65	3.72	4.15	3.72	3.57
	13	3.65	3.88	4.30	4.25	4.06	3.65
	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
	16	3.27	2.74	3.44	3.12	3.50	2.98
	17	3.80	3.12	3.72	3.97	3.68	3.65
	18	4.20	4.56	5.44	4.75	4.96	4.96
	19	4.15	3.65	5.44	4.75	4.96	4.46
	$\bar{x}$	3.64	3.66	3.98	3.97	4.06	3.85

Appendix A-2e: Daily water velocities (fps) recorded near the surface (S) and near the bottom (D) at three points across the downstream end of culvert 5.

	A		B		C	
	S	D	S	D	S	D
April 29	4.20	4.20	4.08	4.45	3.84	4.08
30	3.79	4.38	4.21	4.21	3.92	3.80
May 1	2.93	2.13	2.38	2.43	2.28	2.43
2	4.06	3.37	3.88	4.25	3.80	4.15
3	4.15	3.25	4.06	3.19	3.61	3.25
4	3.57	2.79	3.57	3.14	3.50	2.79
5	3.31	3.14	3.25	3.16	2.98	3.08
6	3.43	2.57	3.13	2.86	2.86	2.66
7	3.14	2.78	2.98	2.81	2.93	2.69
8	2.77	2.40	2.98	3.27	2.98	2.92
9	2.10	2.19	3.12	2.73	2.92	2.54
10	2.46	2.02	2.33	2.58	2.60	2.43
11	3.01	2.43	2.98	3.19	3.05	2.66
12	2.60	2.43	3.34	3.31	3.37	2.98
13	2.92	2.85	3.61	3.50	3.27	3.23
14	-	-	-	-	-	-
15	-	-	-	-	-	-
16	2.98	2.24	2.76	2.66	2.92	2.63
17	2.92	2.82	2.98	3.37	3.10	2.66
18	2.92	3.27	3.97	3.44	3.97	3.37
19	2.98	2.74	3.65	3.31	3.72	3.61
$\bar{x}$	3.17	2.84	3.33	3.26	3.24	3.05

Appendix A-3a. Distance (in feet) from the top of the culvert to the water level at the upstream (U/S) and downstream (D/S) ends of culverts 1-3.

		#1		#2		#3	
		U/S	D/S	U/S	D/S	U/S	D/S
April	29	3.60	2.90	3.50	3.40	3.60	3.40
	30	3.51	3.06	3.60	3.55	3.67	3.54
May	1	3.55	3.00	3.50	3.52	3.65	3.47
	2	3.62	3.13	3.56	3.55	3.65	3.56
	3	3.54	3.16	3.55	3.57	3.85	3.60
	4	3.61	3.10	3.53	3.59	3.85	3.55
	5	3.56	3.05	3.50	3.50	3.65	3.49
	6	3.46	3.05	3.42	3.45	3.79	3.48
	7	3.70	3.20	3.63	3.65	3.80	3.63
	8	3.60	3.28	3.51	3.72	3.86	3.70
	9	3.86	3.35	3.72	3.78	3.95	3.73
	10	3.70	3.28	3.71	3.71	3.91	3.73
	11	3.91	3.41	3.82	3.90	4.00	3.90
	12	4.03	3.54	3.98	4.10	4.23	4.04
	13	4.19	3.72	4.03	4.20	4.37	4.25
	14	4.53	4.10	4.48	4.57	4.66	4.60
	15	3.31	2.84	3.40	3.34	3.50	3.31
	16	3.40	2.90	3.39	3.38	3.54	3.36
	17	3.63	3.16	3.67	3.64	3.75	3.64
	18	4.40	3.98	4.39	4.46	4.59	4.48
	19	4.74	4.26	4.86	4.74	4.92	4.71
	Mean Differences	0.48		-0.03		0.18	

Appendix A-3b. Distance (in feet) from the top of the culvert to the water level at the upstream (U/S) and downstream (D/S) ends of culverts 4 and 5.

	#4		#5	
	U/S	D/S	U/S	D/S
April 30	4.10	3.90	3.90	3.80
May 1	4.50	4.00	4.08	3.98
2	4.15	3.96	3.88	3.91
3	4.15	3.90	3.78	3.79
4	4.13	3.75	3.79	3.64
5	4.07	3.69	3.85	3.61
6	4.01	3.62	3.83	3.55
7	4.12	3.79	4.00	3.69
8	4.72	3.93	4.09	3.80
9	4.24	3.91	3.92	3.81
10	4.20	3.80	3.88	3.69
11	4.41	4.30	4.12	3.93
12	4.61	4.16	4.31	4.10
13	4.94	4.37	4.56	4.27
14	5.20	5.10	5.00	4.94
15	3.83	3.41	3.50	3.34
16	3.92	3.59	3.62	3.51
17	4.40	3.96	4.04	3.86
18	5.24	4.90	4.96	4.71
19	5.43	5.24	5.16	5.08
Mean Difference		0.35		0.16

Appendix B: Details of hoop netting and gill netting operations at Goose Creek, April 27-May 19, 1977.

April 27. Start of fish movement monitoring. Four pike were angled below culverts in the east channel and tagged. Hoop Net #1 was set in east channel just opposite and downstream of culvert #1. Hoop Net #1 was checked in evening. Only a few fish (suckers?) caught. Hole had been cut in the hoop net and some fish may have been removed.

April 28. Hoop Net #1 lifted twice and also reset so it was parallel to current. Gill Net #1 set in east channel above culverts-25 yds of 3" mesh east side and 25 yds of 3" mesh on west side of channel. Gill Net #1 lifted once; no fish as nets were filled with debris.

April 30. Hoop Net #1 lifted in AM and PM. Gill Net #1 lifted, dried, cleaned and reset. No fish is gill nets since they were filled with debris.

May 1. Hoop Net #1 lifted twice; net had to be chopped free ice; no fish. Gill Net #1 frozen in and not lifted.

May 2. Same as May 1, but 3 longnose suckers noted in hoop net in PM.

May 3. Hoop Net #1 frozen in and had to be chopped out.Gill Net #1 (2 nets on west and east sides of channel) also frozen in and couldn't be lifted. Tagged 10 longnose suckers and 3 burbot from Hoop Net #1 in PM.

May 4. Hoop Net #1 lifted in AM and 39 longnose suckers and 2 burbot tagged. Found one gill net (on west side of channel) and lifted it; no fish in gill net. Other gill net still frozen in. Lifted Hoop Net #1 in PM but only one burbot caught, it was not tagged.

May 5. Lifted Hoop Net #1 in AM and tagged 57 longnose suckers and 4 burbot Hoop net had to chopped out of the ice. Hoop net lifted in PM and one burbot tagged. Too cold to set gill nets or second hoop net.

May 6. Hoop Net #1 lifted in PM contained some suckers and burbot but these were not tagged. Set Hoop Net #2 in west channel in AM. The one gill net of Gill Net #1 still frozen in.

May 7. Hoop Net #2 lifted in AM and 229 longnose suckers, 17 burbot, 19 pike and one grayling tagged. Hoop Net #1 also lifted in AM but only 3 longnose suckers caught and these weren't tagged. Set Gill Net #2 and #3 in west channel about 0.3 miles upstream of culverts and were lifted twice. Found and lifted other net of Gill Net #1; net clogged with algae and therefore removed. Not all burbot caught in Hoop Net #2 were tagged.

May 8. Lifted Gill Net #2 and #3. Ice coming downstream and high winds hampered lifting. Hoop Net #2 lifted in AM and 110 longnose suckers and 14 pike tagged. About 50% of AM catch in Hoop Net #2 was burbot, but these were not tagged. Gill Net #2 and #3 checked in PM, but catch light. First tag recapture (a pike). Hoop Net #2 lifted in PM and a few fish tagged.

May 9. Lifted Hoop Net #2 in AM and tagged 81 longnose suckers and 23 pike. Ice damage to wing of Hoop Net #2. Gill Net #2 and #3 lifted in AM-catch light (3 burbot, 2 longnose suckers, 2 pike and one whitefish). Lifted Hoop Net #2 in PM and tagged 45 longnose suckers. Catch very light in Hoop Net #1 and fish not tagged.

May 10. Lifted Hoop Net #2 in AM and PM and tagged 28 pike, 19 longnose suckers, 13 burbot, and one whitefish. Lifted Gill Net #2 and #3 in AM and caught 25 fish. Gill Net #2 and #3 also lifted in PM but no fish caught.

May 11. Hoop Net #2 knocked out by ice during the night and was reset. Fish tagged from Hoop Net #2 were 9 pike, 5 longnose suckers and one grayling. Lifted Gill Net #2 and #3 in AM and PM. Other gill net of Gill Net #1 retrieved and reset. Catch still poor in Hoop Net #1.

May 12. Hoop Net #2 lifted and 19 pike, 14 burbot, 6 longnose suckers and one whitefish tagged. Catch light in Hoop Net #1-one longnose sucker tagged. Hoop Net #1 lifted and reset opposite culvert #2.

May 13. Hoop Net #2 lifted and 17 pike, 17 burbot, 4 longnose suckers and one whitefish. No fish caught in Hoop Net #1. Three round whitefish caught in Gill Net #2 and #3 and one longnose sucker caught in Gill Net #1. Began checking burbot stomachs for fish eggs and and detailed sampling of fish caught in gill net sets.

May 14. Tagged 5 pike, one longnose sucker, and burbot, caught in Hoop Net #2. No fish in Hoop Net #1.

May 15. No fish tagged. Set a gill net downstream of culverts in east channel.

May 16. Lifted downstream gill net-no fish caught. Sampled fish caught in Hoop Net #2. No fish caught in Hoop Net #1. Both hoop nets left in. Lifted upstream gill nets. Set a gill net downstream of culvert in west channel.

May 17. Lifted downstream gill net-caught 2 round whitefish and one longnose sucker.

May 18. Few fish caught in hoop nets. Set 125 yds of 3" gill net in Warkworth Lake.

May 19. Catch in hoop nets poor and hoop nets removed. Twenty-seven fish caught in gill net set in Warkworth Lake.

Appendix C: Fork length, sex and gonad condition of northern pike sampled at Goose Creek from May 13-19, 1977.

Date	Fork Length (cm)	Sex	Gonad Condition*				
			1	2	3	4	5
May 13	40.0	M				x	
14	54.0	M				x	
15	36.0	F			x		
"	53.3	F		x			
"	57.5	F	x				
"	50.0	M					x
"	39.0	M	x				
"	37.5	M	x				
"	39.9	M					x
"	37.5	M					x
"	40.0	M					x
"	48.5	M					x
"	66.9	F			x		
"	65.0	F					x
16	53.0	M					x
"	46.0	M					x
"	63.0	F	x				
"	58.0	M	x				
"	70.0	F					x
"	48.0	M					x
17	86.5	F			x		
"	58.5	M				x	
"	43.0	M		x			
"	52.0	F			x		
"	57.0	M					x
"	57.0	F					x
"	56.0	F				x	
"	52.0	M				x	
"	61.0	F				x	
"	47.0	M	x				
18	68.5	F			x		
"	57.5	M					x
"	65.0	F				x	
"	60.0	F				x	
"	61.0	M					x
"	64.0	F					x
"	43.0	M					x
"	43.0	M		x			
"	42.0	M		x			
"	43.5	M		x			
"	39.0	M					x
19	-	F					x

* See Table 20

Appendix D: Fork length, sex and gonad condition of longnose suckers sampled at Goose Creek from May 14-19, 1977.

Date	Fork Length (cm)	Sex	Gonad Condition*				
			1	2	3	4	5
May 14	46.0	F				x	
15	45.0	F			x		
16	37.5	M	x				
"	41.5	M	x				
"	42.5	M	x				
"	39.5	M	x				
"	40.0	F	x				
"	41.8	F					x
"	49.0	F					x
"	46.5	F	x				
17	46.0	F	x				
"	48.0	F					x
"	45.0	F				x	
"	43.0	F		x			
"	46.0	F					x
"	44.5	M					x
"	33.0	M		x			
17	44.0	F		x			
19	-	F				x	
"	-	-	x				
"	-	-	x				
"	-	M				x	
"	-	M					x
"	-	-	x				
"	-	M					x
"	-	M					x
"	-	F			x		
"	-	M					x
"	-	F	x				
"	-	M					x
"	-	F				x	
"	-	F				x	
	-	M					x

* See Table 20

Appendix E: Computations for Schnabel and Schumacher population estimates for northern pike in Goose Creek, from hoop net sets in both channels.

Date	No. caught (C_t)	No. recaptured (R_t)	No. marked (M)	Marked fish at large (M_t)	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t
Apr. 28	32	0	32	0	0	0	14,336	0.2857
29	14	2	14	32	448	64	23,276	0
30	11	0	9	46	506	0	-	0
May 1	0	0	0	55	0	0	-	0
2	0	0	0	55	0	0	-	0
3	0	0	0	55	0	0	-	0
4	0	0	0	55	0	0	-	0
5	0	0	0	55	0	0	-	0
6	0	0	0	55	0	0	-	0
7	22	0	22	55	1,210	0	66,550	0
8	16	1	16	77	1,232	77	94,864	0.0625
9	23	1	23	93	2,139	93	198,927	0.0435
10	28	4	28	116	3,248	464	376,768	0.5714
11	9	1	9	144	1,296	144	186,624	0.1111
12	19	1	19	153	2,907	153	444,771	0.0526
13	17	0	17	172	2,924	0	502,928	0
14	5	1	5	189	945	189	178,605	0.2000
Totals	196	11	194	1,407	16,855	1,184	2,087,649	1.3268

Appendix F: Computations for Schnabel and Schumacher population estimates for northern pike in Goose Creek, from hoop net set in west channel.

Date	No. caught (C_t)	No. recaptured (R_t)	No. marked (M)	Marked fish at large (M_t)	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t
May 7	22	0	22	0	0	0	0	0
8	16	1	16	22	352	22	7,744	0.0625
9	23	1	23	38	874	38	33,212	0.0435
10	28	4	28	61	1,708	244	104,188	0.5714
11	9	1	9	89	801	89	71,289	0.1111
12	19	1	19	98	1,862	98	182,476	0.0526
13	17	0	17	117	1,989	0	232,713	0
14	5	1	5	134	670	134	89,780	0.2000
Totals	139	9	139	559	8,256	625	721,402	1.0411

Appendix G: Computations for Schnabel and Schumacher population estimates for longnose suckers in Goose Creek, from hoop net sets in both channels.

Date	No. caught (C_t)	No. recaptured (R_t)	No. marked (M)	Marked fish at large (M_t)	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t
Apr. 28	4	0	4	0	0	0	0	0
29	58	0	58	4	957	0	3,828	0
30	51	0	51	62	3,162	0	196,044	0
May 1	0	0	0	113	0	0	0	0
2	0	0	0	113	0	0	0	0
3	10	0	10	113	1,130	0	127,690	0
4	38	0	38	123	4,674	0	574,902	0
5	57	0	57	161	9,177	0	1,477,497	0
6	0	0	0	218	0	0	0	0
7	229	0	229	218	49,922	0	10,882,996	0
8	109	1	109	447	48,723	447	21,779,181	0.00917
9	126	5	126	556	70,056	2,780	38,951,136	0.19841
10	19	0	19	682	12,958	0	8,837,356	0
11	12	3	12	701	8,412	2,103	5,896,812	0.75000
12	7	2	7	713	4,991	1,426	3,558,583	0.57143
13	4	2	4	720	2,880	1,440	2,073,600	1.00000
14	1	1	1	724	724	724	524,176	1.00000
Totals	725	14	725	5,668	217,766	8,920	94,883,801	3.52901

Appendix H: Computations for Schnabel and Schumacher population estimates for longnose suckers in Goose Creek, from hoop net set in west channel.

Date	No. caught (C_t)	No. recaptured (R_t)	No. marked (M)	Marked fish at large (M_t)	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t
May 7	229	0	229	0	0	0	0	0
8	109	1	109	229	24,961	229	5,716,069	0.00917
9	126	5	126	338	42,588	1,690	14,394,744	0.19841
10	19	0	19	464	8,816	0	4,090,624	0
11	5	2	5	483	2,415	966	1,166,445	0.80000
12	6	1	6	488	2,928	488	1,428,864	0.16667
13	4	2	4	494	1,976	988	976,144	1.00000
14	1	0	1	498	498	0	248,004	0
Totals	499	11	499	2,994	84,182	4,361	28,020,894	2.17425

Appendix J: Stomach contents of adult northern pike, Arctic grayling, lake whitefish, round whitefish and burbot captured in Goose Creek during May, 1977.

	N. Pike	A. Grayling	L. Whitefish	R. Whitefish	Burbot
No. of Fish Examined	39	12	8	15	8
No. of Empty Stomachs	13	-	1	5	4
FOOD ITEMS					
Fish					
-Stickleback	18	3	-	-	2
-Shiners	4	-	-	-	-
-N. Pike	4	-	-	-	-
-Burbot	1	-	-	-	-
-Suckers	14	-	-	-	-
-Fish Eggs	1	-	-	-	1
Invertebrates					
-Gastropods	-	-	3	1	-
-Dipterans	-	6	2	8	-
-Hemipterans	-	3	-	1	-
-Coleopterans	-	1	-	1	-
-Trichopterans	-	3	2	1	-
-Leeches	-	-	-	1	-
Algae	-	-	1	-	-
Unidentified Material	-	-	-	-	1